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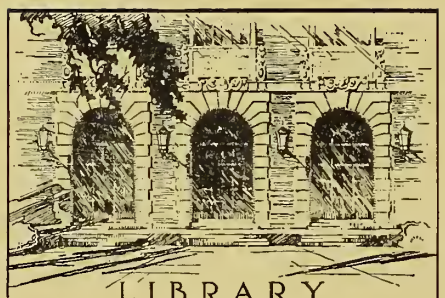

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CIVIL ENGINEERING STUDIES
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THE TURBIDITY OF PUBLIC SWIMMING POOL WATERS

By
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CHAPTER I.

INTRODUCTION

In the design and operation of swimming pools there are two main objectives. One of these is the provision for equipment to maintain adequate clarity of the water and the other is prevention of the transmission of disease through proper disinfection. If these two objectives cannot be met, there would be little reason to build swimming pools since natural bathing areas would suffice. Proper temperature and the absence of color and odor may be of concern but are of considerably less importance than clarity and disinfection. It is with the first objective stated, the ability to maintain clear water, with which this paper is concerned.

Perhaps the most obvious reason for desiring a clear water is to eliminate safety hazards involved with turbid or non-clear water. The life-guards and other persons near the water must be able to see and distinguish persons in distress. In addition, swimmers and particularly competitive swimmers must be able to see quite well while under the water. The present swimming pool standards for clarity involve the ability to see a submerged disc which supposedly reflects the ability to see a submerged swimmer.

The other reason for providing clear water in the swimming pool is one that is attaining more and more prominence in the water treatment and pollution control fields. This reason is based on aesthetics or the fact that a turbid water does not look good or does not appeal to the prospective swimmer. Not only would the swimmer not like the looks of turbid pool water but perhaps he would also suspect a poor attitude towards general sanitation considerations by the owner as to other aspects of pool operation including dressing room and snack bar sanitation.

Objectives of the study include:

1. A statistical analysis of the turbidities of swimming pool water. A survey was made to determine the range of turbidities encountered in public swimming pool waters. As many samples as practical were obtained and analyzed from as large an assortment of pools as was possible during the summer swimming pool season of 1966. The average turbidity, standard deviation, and a frequency distribution of the turbidities were obtained.
2. To provide the necessary information for recommending a pool water quality criterion for clarity and an improved technique for measuring and expressing turbidity. It was felt that the presently available methods for determining acceptable clarity are awkward and unreliable.
3. To compare the turbidities of different groups of swimming pools. Information was available so that the swimming pools could be divided into various categories including the type of filter provided and ownership. In addition, it was possible to separate the samples as to whether they were taken at the deep or shallow end of the pool or from wading pools and to separate the indoor from the outdoor pools. Thus, one can compare results of the turbidity analyses from one of these categories to another.
4. To attempt correlations between turbidity analyses and swimming pool operational data. It was possible to obtain operational data such as chlorine residual, number of persons in the pool, pH, and bacteriological test results for each of the samples. Correlations were made between the turbidities and these variables.

CHAPTER II.

HISTORICAL REVIEW

At the beginning of the twentieth century, pool operators became concerned about the high cost of operating pools on a fill and draw basis. Until that time the pools were operated much like bath tubs in that the water was drained and refilled at regular intervals. Other pools operated on a continual flow-through basis with no recirculation or filtration of water. High operational costs made it necessary to install filtration equipment so that the pool water could be reused. The filtration equipment was installed to maintain adequate water clarity. Since the application of chlorine should be sufficient for immediate disinfection in the pool, the capabilities of the filtration systems to remove bacteria are of secondary importance. Though pool operators and owners, as well as public health personnel, have been concerned about the clarity of swimming pool waters for some time, little information pertaining to the turbidity of swimming pool water is available.

In one of the few articles which mentions turbidity measurements of pool water, Kiker (1) reports on the suitability of diatomite filters for swimming pool operations. In this article, a swimming pool at the University of Florida equipped with pressure diatomaceous earth filters was operated at various filter rates and with various amounts of precoat and body feed. Of primary interest is the following:

> Throughout the test, the filters were practically 100% efficient in the removal of turbidity from the recirculated water. The turbidity of the filter influent ranged from less than one to approximately 20 ppm, depending upon the amount of diatomite added continuously to the water and the amount of algae that had been permitted to develop in the pool. Without exception,

> during the period of test, the turbidity of the filter effluent was reduced to zero within 60-90 seconds after the filter had been placed in operation.

No mention is made of the means for determining the turbidity. However, it is improbable that the turbidity was zero.

An article by Jackson and Hutto (2) compares a diatomaceous earth filter and a sand filter both installed at the same pool. The 40,000 gallon pool was recirculated at a 95 gallon per minute rate. The diatomaceous earth filter provided by the authors' company was a 90 square foot vacuum diatomite unit whereas the rapid sand filter provided for the original pool installation was 4.5 square feet in area and was "recommended for this specific size pool by the manufacturer". Thus, the rate of flow through the filters was near 1.06 gallons per minute per square foot for the vacuum diatomite filter and 21.1 gallons per minute per square foot for the rapid sand filter. The authors state the results of this test proved that the vacuum diatomite filter is the better filter based on overall cost as well as the ability to maintain adequate clarity. It was reported that the pressure sand filter needed to be back washed several times a day and the effluent turbidity was considerably above that of the vacuum diatomite filter effluent. Only once was the filter effluent from the sand filter below 1.0 parts per million of turbidity while the diatomite filter maintained the turbidity consistently below 1.0 ppm. Since the method of determining the turbidity was not mentioned in the article, one can not relate these results with those reported in this paper. The results of turbidity measurement were reported as parts per million rather than Jackson Turbidity Units.

In another article, Jackson (3) discusses the results of turbidity measurements from five pools. Three 40,000 gallon pools one of which was operated on a fill and draw basis were compared. The other two were

equipped with a 90 square foot vacuum diatomite filter operating at one gallon per minute per square foot while the other was equipped with a 25 square foot pressure sand filter operating at 3.3 gallons per minute per square foot. For these three pools the sand filter pool was the most turbid, followed by the fill and draw pool and by the vacuum diatomite pool. However, it is suggested that the fill and draw pool never reached an adequate turbidity of 1.0 parts per million, and the vacuum diatomite pool was at or below 1.0 ppm less than one-half the time the pools were in operation. The author also compares two 120,000 gallon pools, one equipped with an 84 square foot pressure diatomite filter operating at a flow rate of 3.0 gallons per minute per square foot and a sand filter with an area of 116 square feet operating at a rate of 2.7 gallons per minute per square foot. The turbidity of the two pools were quite similar all being below 0.6 ppm of turbidity with the turbidity reported as parts per million rather than Jackson Turbidity Units.

CHAPTER III.

THEORETICAL CONSIDERATIONS

Various researchers in both sanitary engineering and chemistry have attempted to develop a satisfactory means for determining the turbidity of water and other liquids. The original methods such as those related to the depth of water required for the disappearance of a standard object such as a platinum wire or the outline of a candle flame are strictly empirical. These results are normally reported as parts per million or milligrams per liter of silica or Jackson Turbidity Units. The next step in the development of turbidity measurement was the development of a nephelometer. However, many of the nephelometric turbidity analyses were standardized to results obtained by empirical means. The last step in the development of turbidity measurement was absolute turbidity measurement (4). Results of such analyses may be described in terms of the logarithm of the ratio of incident to transmitted light with no reference to the concentration of suspended solids of a standard material.

One of the earliest methods of turbidity analysis was the U.S. Geological Survey turbidity rod. The turbidity rod consisted of a calibrated rod to one end of which a fine platinum wire of 1 mm diameter was attached at right angles to the rod. Cox (5) describes the procedure as follows:

> To obtain the turbidity of the water with this instrument, the rod is lowered vertically in the water being tested. The observer places an eye immediately above and watches the platinum wire as the rod is being lowered into the water. He notes the moment the wire disappears from sight or is no longer visible through the water.
>
> The position of the surface of the water is read on the calibrated scale of the rod. For example, if the rod is

> lowered and the wire is no longer visible to the observer when the water surface has reached the 100 mark on the rod, the turbidity is 100 parts per million.

Cox doesn't state the method of calibration. It is assumed that standard suspensions of Fuller's earth or other clays were used to calibrate the rod.

The basis for most analyses in the water treatment field has been the Jackson Candle Turbidimeter which is another empirical means of determination. The Manual on Industrial Water and Industrial Waste Water (4) describes the Jackson Candle Turbidity as "an empirical measure of turbidity in special apparatus, based on the measurement of the depth of a column of water sample that is just sufficient to extinguish the image of a burning standard candle observed vertically through the sample".

This method is limiting in that its lower limit is 25 Jackson Turbidity Units (formerly parts per million silica) which is considerably higher than most finished waters and considerably higher than the turbidity of swimming pool waters. Sawyer (6) discusses the transition from parts per million silica to Jackson Turbidity Units. Baylis (7) and Weir (8) attacked this disadvantage of the Jackson Candle Turbidimeter by developing means for determining lower turbidities. Both researchers noted specifically the need for determining these low level turbidities. Baylis, in particular, reported his concern for the problem after watching the performance of a "bathing beauty" in a swimming pool. The methods proposed by Baylis and Weir are based on visual comparison of an unknown sample with a standard sample, the turbidity of which is calculated by diluting a standard sample for which the turbidity is determined by the Jackson Candle Turbidimeter.

Empirical methods have been devised for determining swimming pool water clarity. These methods, however, are rather awkward in that they

must be performed at the pool. In addition, the results are either positive or negative in that the pool water is declared either safe or hazardous. Thus, no relative values can be obtained.

The American Public Health Association requirement as adopted by the Illinois Department of Public Health (9) is as follows:

> A black disc, 6 inches in diameter on a white field, when placed on the bottom of the pool at the deepest point, must be clearly visible from the sidewalks of the pool at all distances up to 10 yards, measured from a line drawn across the pool to the disc.

The National Swimming Pool Institute standard for public pools, adopted in 1960 (10), states:

> The water shall have a degree of clarity such that a disc 2 inches in diameter which is divided into quadrants in alternate colors of red and black shall be clearly discernable through 15 feet of water and the different colors readily distinguishable.

The use of a photocell in the measurement of the transmission of light through water samples for finished water from a water treatment plant was reported as early as 1926 by Scott (11). However, most of the development and research of electronic methods for determining light scattering characteristics of suspended solids has been done since World War II. The works of Oster (12,13), Barnes and Stock (14), Knight (15), and Rose (16) have all provided a considerable amount of information.

The use of the photocell as described by Scott, to measure the amount of transmitted light probably led to the development of the measurement of scattered light. In samples with low turbidity, the amount of light transmitted is so close to the total amount of incident light that the difference is barely discernable. Thus, there was a need for measuring scattered rather than transmitted light. The nephelometer is described in the Manual on Industrial Water and Industrial Waste Water (4) as follows:

> An empirical measure of turbidity based on the measurement of the light scattering characteristics (Tyndall effect) of the particulate matter in the sample (Note 1.)
>
> Note 1--The measurement of nephelometric turbidity is accomplished by measuring the intensity of scattered light at 90° to the incident beam of light. Numerical values are obtained by comparison of the light scattering characteristics of a known or arbitrarily chosen material and an equivalent optical system. Comparison may also be made between transmitted light effect and scattered light effect.

The nephelometer offers at least two advantages. First is the ability to measure turbidities considerably lower than that possible with the Jackson Candle Turbidimeter. The second advantage is the relative low cost of the instrument. However, there are also disadvantages. One is the problem of choosing a standard suspension since clays, diatomaceous earth and other suspensions vary considerably in their physical properties. Thus, it is impossible to choose a standard suspension which will give the same results time after time. Another disadvantage in regard to the standardization of the device is the inability to rely upon standard dilution techniques for samples used for calibration. Many factors, the effects of which may not be entirely understood, can influence the results. For example, as one dilutes a clay suspension from 100 Jackson Turbidity Units as measured on the candle turbidimeter, the effects of solubility of the clay, when diluted to less than one Jackson Turbidity Unit and even down to less than 0.1 of a unit are usually not considered. Not only may the standard suspension be entirely soluble at these extremely low concentrations, but the size, shape, and natural coagulation properties may change sufficiently to disproportion the dilution factor.

Additionally, as pointed out by Black and Hannah (17), light scattered by low turbidity suspensions is not symmetrical and, in fact, more light may be scattered at 15° than at 90°. This prevents good linear correlation

between the results obtained by the instrument and the results theoretically determined from the so-called standard suspension material.

The third type of turbidity measurement described in the manual (4) is absolute turbidity measurement. It is described as, "The fractional decrease of incident, monochromatic light through the sample integrating both scattered and transmitted light". This type of measurement can be considered as the name indicates--an absolute measurement of the total amount of scattered light at all angles as the light is passed through the sample. This type of measurement does not necessarily depend upon comparison with known suspensions. The problems involved in calibrating a machine of this type to known suspensions would be the same as those described above for the nephelometric turbidimeter.

Even though it is obvious from the literature that the absolute turbidity measurement utilizing an integrating sphere photometer is the best means presently available for measuring turbidity, a nephelometric device was used in this study. The nephelometer does provide good relative determinations. The instrument used in this experimentation was the Model 1860 Turbidimeter manufactured by the Hach Chemical Company of Ames, Iowa and is described in greater detail in Appendix A. The primary reason for choosing a lesser quality of instrument was the price of the commercially available devices. The nephelometer used in the experiment is available for just under $300.00 whereas the integrating sphere photometer costs approximately $3000.00.

CHAPTER IV.

PROCEDURES

Since a great proportion of this paper involves statistical analyses, it was necessary to obtain a considerable number of samples so that the results might be statistically significant. With this in mind, it was decided that all of the sampling and analyses be performed during the summer swimming pool season so that both indoor and outdoor pools might be included. In order that there might be some similarity in regard to general construction and equipment capabilities, it was decided that only public swimming pools should be sampled. All public swimming pools within the state of Illinois are controlled by the Illinois Swimming Pool Act as administered by the Illinois Department of Public Health. Thus, all pools must meet certain minimum sanitary requirements (9). In addition, samples from public swimming pools were readily available. All public swimming pool operators must submit routine samples for bacteriological analyses to the regional laboratories of the State Health Department on a bi-weekly basis. Arrangements were made with the local Champaign laboratory to retain an adequate amount of each sample sent to the laboratory after sufficient water was removed for bacterial analyses. Usually, the samples arrive at the laboratory the day after they are mailed in by the operators. Some local samples and others collected by near-by local health departments are brought to the laboratory immediately after collection. The samples were refrigerated until picked up or transferred to the Health Service Laboratory for turbidity analyses.

Normally, each operator submits two or three samples. One sample is obtained from the shallow end of the pool, one from the deep end of the

pool and one from the wading pool, if present. For each sample submitted, a complete report sheet is filled out by the operator indicating the location of the sample as well as operational data. Information such as the number of swimmers, the number of swimmers during the past 12 hours, chlorine residuals, etc. were thus obtained for each sample. A sample report form is included on page 13. The sample containers were numbered corresponding to the State Laboratory report sheet. Thus, it was possible to determine the turbidity of each individual sample with no prejudice since the origin of the sample was not known at the time of analysis.

With the assistance of the East Central Regional Office of the Illinois Department of Public Health, information concerning pool size, type of filter system, and pool locations were compiled for all of the pools. Samples were obtained from 102 swimming pools located in 37 municipalities and 18 counties in East Central Illinois. A tabulation of the locations by municipalities is included on page 14. A table listing the different categories or groups of pools is included on page 14.

Each sample obtained during the survey was analyzed for turbidity with the Hach Model 1860 turbidimeter. The procedure for turbidity analysis is included in Appendix A.

Because of the vast amount of statistical analyses desired for this project, it was necessary to utilize the Statistical Service Unit of the University of Illinois. It was decided to determine averages, standard deviations, frequency distributions, and correlations for turbidity with construction and operational variables. All of the data were compiled and a program designed for the International Business Machine 7094 computer.

STATE OF ILLINOIS
DEPARTMENT OF PUBLIC HEALTH
SPRINGFIELD

MAIL SAMPLES IMMEDIATELY
SPECIAL DELIVERY

LAB. NO._____ SP

DATE RECEIVED_____

USE SOFT PENCIL ONLY — DO NOT USE INK

COLLECTOR:

COLLECT SAMPLES ONLY WHEN THERE ARE SWIMMERS IN THE POOL.
FILL IN THIS BOX ONLY—PRINT WITH SOFT BLACK PENCIL (DO NOT USE INK)
FILL IN ONE SHEET FOR EACH SAMPLE—WRAP WITH BOTTLE TO WHICH IT PERTAINS

DATE COLLECTED:_____ HOUR:_____

TOWN:_____ COUNTY:_____

NAME OF POOL:_____

COLLECTED BY:_____

COLLECTION POINT (ENCIRCLE): SHALLOW; MIDDLE; DEEP.

MAIL RESULTS TO:

NAME:_____

STREET:_____

TOWN:_____ ILLINOIS

OPERATION DATA

AT TIME OF SAMPLING:

WATER APPEARANCE:_____

PH:_____ TEMPERATURE:_____

NO. OF SWIMMERS:_____

NO. DURING PAST 12 HOURS:_____

DISINFECTANT RESIDUALS:

SHALLOW_____ PPM DEEP_____ PPM

DURING PAST 24 HOURS:

RECIRCULATION STOPPED_____HOURS

NEW WATER ADDED_____GALLONS

CHEMICALS ADDED_____

REMARKS:_____

(USE SEPARATE SHEET OF THIN PAPER FOR FURTHER REMARKS)

—WRAP THIS SHEET OUTSIDE OF PACKING, FOLD ONLY WHERE FOLDED. DO NOT WRITE ON REVERSE SIDE.—

DO NOT WRITE IN SPACE BELOW

CHEMICAL RESULTS EXPRESSED AS PPM								
NI-TRATE	ALKALINITY P	ALKALINITY TOTAL	pH	HARD-NESS	IRON FE			

C

E

10	1	0.1	.01	.001	.(4)	.(5)	AZIDE

SED.	TURB.	ODOR		
			COLIFORM (MPN/100 ml)	
			ENTERO. (MPN/100 ml)	
			BACTERIA PER ML	
			STREPTOCOCCI	

HEMOLYSIS ALPHA BATA

REPORT OF ANALYSIS

SATISFACTORY

THE WATER WAS OF SATISFACTORY BACTERIOLOGICAL QUALITY FOR SWIMMING AT TIME OF SAMPLING.

NOT ENTIRELY SATISFACTORY

THE BACTERIAL COUNT WAS ABOVE THAT CONSIDERED SATISFACTORY.

UNSATISFACTORY

THE WATER CONTAINED POLLUTIONAL ORGANISMS POSSIBLY OF INTESTINAL ORIGIN AND WAS OF UNSATISFACTORY QUALITY FOR SWIMMING.

STREPTOCOCCI ORGANISMS WERE FOUND INDICATING UNDESIRABLE CONTAMINATION OF NOSE AND THROAT ORIGIN.

SEE OTHER REPORT SHEET, OR ACCOMPANYING LETTER, FOR OPINION ON QUALITY OF THIS POOL WATER.

RECOMMENDATIONS

THIS ANALYSIS RESULT SHOWS THE NEED FOR CAREFUL CONTROL OF THE DISINFECTANT DOSAGE IN ORDER TO MAINTAIN FREE RESIDUALS OF NOT LESS THAN 0.5 P.P.M. IN ALL PARTS OF THE POOL WHEN THE POOL IS IN USE.

THE PH VALUE SHOULD BE MAINTAINED ABOVE 7.0 BUT NEVER HIGHER THAN 7.6.

EXERCISE SUPERVISION OVER BATHERS TO INSURE THAT CLEANSING, NUDE SHOWERS ARE TAKEN BY EVERYONE BEFORE ENTERING THE POOL AREA.

FIGURE 1. ILLINOIS DEPARTMENT OF PUBLIC HEALTH SWIMMING POOL REPORT SHEET.

TABLE 1

LOCATION OF POOLS BY MUNICIPALITY

Altamont - 1	Lexington - 1
Bement - 1	Marshall - 1
Bloomington - 14	Mattoon - 2
Casey - 1	Monticello - 1
Champaign - 12	Newton - 1
Charleston - 2	Normal - 5
Clifton - 1	Oakland - 1
Clinton - 5	Paris - 1
Danville - 11	Pontiac - 1
Deland-Weldon - 1	Rantoul - 2
Effingham - 7	Robinson - 1
Fairbury - 1	Rossville - 1
Fairmount - 1	Stanford - 1
Farmer City - 2	Sullivan - 2
Georgetown - 1	Tuscola - 2
Gibson City - 1	Urbana - 10
Gridley - 1	Watseka - 1
Hoopeston - 1	White Heath - 1
LeRoy - 2	

TABLE 2

POOL CATEGORIES

Total Pools - 102	
A. Location	
Indoor	23
Outdoor	79
B. Filter System	
Sand	52
Pressure diatomite	35
Vacuum diatomite	13
C. Ownership	
Governmental agency (city, park district, etc.)	23
Motel	22
School	12
Private club (includes country clubs, private swim clubs, and apartments)	33
Private organization (YMCA, YWCA, and church pools)	12

CHAPTER V.

RESULTS

In order to relate the results of turbidity analyses to visual clarity it was necessary to personally observe a pool at the time of sample collection. To do this, it was decided to choose a swimming pool with ordinarily excellent clarity and to allow the turbidity to increase naturally by eliminating the filtration of the water. A University of Illinois pool was chosen for this procedure. Water was continuously re-circulated and chlorinated during the experiment to insure a bacteriologically safe pool. The results of this experiment are outlined in detail in Appendix B.

As is reported in Appendix B the following grades or classifications of pool clarity with corresponding ranges of turbidity are suggested as follows:

0 - 0.099 JTU	Excellent clarity
0.100 - 0.299 JTU	Adequate clarity, although this turbidity may be noticeable to the trained eye
0.300 - 0.699 JTU	Noticeably turbid, even to the untrained eye
Greater than 0.700 JTU	Unacceptable

These suggested ranges of turbidity and their corresponding visual appearances were made according to the concensuses of opinions expressed by the pool operator, the swimming instructor and the author of this paper. A much better arrangement would have been to have had an impartial group of persons judge the appearance of the pool. Obviously, both the pool operator and the swimming instructor were quite proud of the normal excellent clarity of the pool water. Any slight change in the turbidity would therefore be noticed or possibly imagined. This is particularly true since the pool

operator and swimming instructor both knew that the filters were being bypassed. It is noted in Appendix B that some prospective swimmers refused to swim in the pool when the turbidity was somewhere between 0.463 and 0.574 JTU. The real reasons for their refusal to swim in the pool are not known. Perhaps, they had been swimming in this same swimming pool for some time and had been accustomed to the excellent clarity. They might have assumed for example that none of the pool equipment was operating satisfactorily since there was a noticeable increase in turbidity. It may well be that the same people would not refuse to enter another pool under different circumstances with the same turbidity. Additional work needs to be done with other swimming pools of different sizes, locations and types of filtration systems in order to set a definite water quality criterion for swimming pool water.

The results of all statistical analyses are tabulated in Appendix C. A tabulation of the results of statistical analyses of the variables of pool operation and control comprise the first 13 pages. A brief description of each of these variables follows:

1. Turbidity. The turbidity is given in terms of Jackson Turbidity Units as determined by the Hach Model 1860 Turbidimeter.
2. Turbidity Load Factor. The number reported as the Turbidity Load Factor (TLF) is the turbidity divided by the number of persons using the swimming pool during the twelve hours previous to sample collection per thousand gallons of pool volume. This factor was devised in an attempt to quantitate the amount of suspended solids added to a swimming pool for each swimmer taking into account the dilution available. In

other words, the higher the turbidity load factor, the greater the amount of turbidity added by each person using the pool.

3. pH. pH results used in this tabulation are as determined by an electric pH meter at the State Health Department Laboratory.
4. Temperature (degrees Fahrenheit). This temperature is the temperature of the pool water as measured and reported by the pool operator.
5. Number of swimmers. The number of swimmers which were in the pool at the time of sample collection.
6. Number of swimmers during the previous twelve hours. The total number of swimmers using the swimming pool during the 12 hours prior to sample collection.
7. Number of swimmers per 1000 gallons. The number of swimmers (Item 5 above) divided by the pool volume in thousands of gallons.
8. Number of swimmers during the 12 hours previous to sample collection per one thousand gallons of pool water. This is Item 6 divided by the pool capacity in thousands of gallons.
9. Chlorine residual. The chlorine residual as reported on the swimming pool report form by the pool operator.
10. Coliform. Unfortunately all of the bacteriological analyses for coliform organisms were analyzed by the five-tube lactose broth method so that the exact number of bacteria were not determined. For this reason, the averages and standard deviations are not statistically correct. The results of the five-tube method were reported as 5 -, 1+, 2+, 3+, 4+, and 5+

depending upon the number of positive tubes, if any. For the purpose of this study, a five minus sample or a negative sample was assigned the value of 1, a "1+ sample" was assigned the value of 2, and so on until a "5+ sample" was assigned the value of 6. Thus, an average of 1.000 would indicate that all of the samples were negative (or 5-). Likewise, an average of 2.000 would indicate that the samples averaged 1+. Any results reported as just slightly higher than 1, which is true for all but a few of the results, would indicate that most all of the samples were negative. Admittedly, the use of the most probable number of coliforms would be preferable. However, this possibility was not thought of until it was too late for incorporation in the statistical analyses.

11. Total bacteria. Total bacteria per milliliter as determined by actual count. However, the total bacteria count was determined for only approximately 29 per cent of the samples.
12. Streptococci. As in the coliform statistics, streptococci were determined by adding portions of the samples to test tubes. Only two tubes were used so the results were 2-, 1+, or 2+. These results were assigned values of 1, 2, and 3 respectively so that the values given for the average of the streptococci analyses do not represent a true average.
13. Pool size. The pool sizes in gallons were obtained from the Illinois Department of Public Health.

The first 7 pages of the statistical analyses (pages 57 to 63) have been compiled with all of the samples taken into consideration. However,

after this information had been compiled, it was noted that there was a considerable difference in the turbidity of the wading pools as compared with the rest of the samples. It was decided to eliminate all the wading pool samples from the statistical analyses for the following reasons:

1. The wading pools are quite often heavily loaded with respect to the main pools.
2. The water is normally not deep, which would allow for the wading pools to operate at higher turbidities.
3. Although the wading pools are fed from the same water treatment system, their appearance does not reflect the clarity of the main pool waters.

Since the inclusion of wading pool samples might be detrimental to the over-all results of the study, those results were placed aside and statistical analyses of the remaining sample results were performed and reported on pages 64 to 69.

For each variable, the average, standard deviation, and number of samples have been compiled. In addition to this, the correlation coefficients of the variables compared with both the turbidity and Turbidity Load Factor are recorded in the last two columns of pages 57 to 69.

Page 64 lists the results of the statistical analyses of all samples with the exception of those from wading pools. The average turbidity was 0.309 Jackson Turbidity Units even though over 60 per cent of the samples were beneath the average. The general trend in the results of statistical analyses for turbidity is a fairly high standard deviation as well as a fairly high average. This is due to the fact that many of the results were relatively low but the few high results increased the averages significantly and skewed the frequency distribution curves. A frequency distribution curve

of these samples is included on page 21. The only other item perhaps worth mentioning in regard to this particular page of results is the rather low number of swimmers per thousand gallons of pool water. Based on the average of 0.361 swimmers per thousand gallons of pool water, it is, of course, obvious that there was nearly three thousand gallons of water on the average available for each swimmer. This would allow for a considerable dilution of any suspended solids added by the swimmers.

Most of the formulas used to determine the maximum number of bathers in a swimming pool are based on pool surface area rather than volume. Depending upon the percentage of swimmers assumed to be on the decks surrounding the pool and the depth of the water, the area required for each swimmer ranges from 10 to 36 square feet (18). Assuming an average depth of 4 feet in the shallow areas and an average depth of 8 feet in the deep areas, the volume of water for each swimmer would range from 300 to 2160 gallons. Thus the pools in the survey were loaded at between one tenth and two thirds of their capacities depending upon the area specified for each swimmer.

The trend throughout the results of the statistical analyses is the almost complete lack of correlation between the turbidity or Turbidity Load Factor and any of the variables which were recorded. In other words, generally speaking, there were no significant correlations between turbidity and the number of swimmers, chlorine residual, or bacterial determinations. There are a few isolated cases of significant correlations. However, where one variable can be significantly correlated as for the Turbidity Load Factor and total bacteria for motel pools; there is no correlation between total bacteria and the Turbidity Load Factor for other categories of ownership. The reason for this, apparently, is the low number of samples in the motel category.

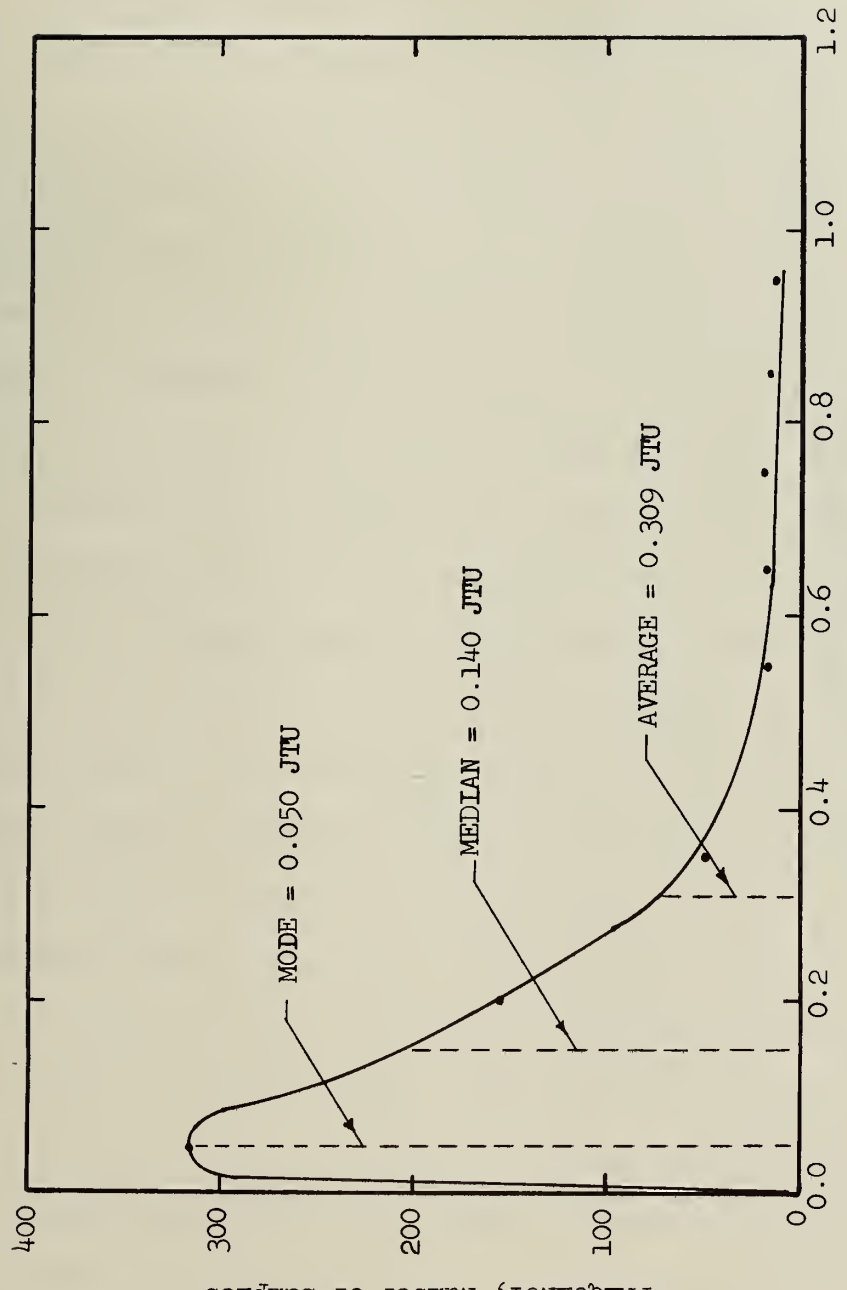

FIGURE 2. FREQUENCY DISTRIBUTION OF TURBIDITIES FOR ALL CATEGORIES EXCLUDING WADING POOL SAMPLES.

The lack of correlation between turbidity and the factors studied indicates that none of the variables were responsible for changes in turbidity. Thus, other items such as unsanitary dressing rooms, windblown dust and dirt, formation of chemical precipitates, and malfunctions of the filtration equipment must be responsible for changes in turbidity.

Interesting information can be obtained by analyzing the accumulative frequency distributions of turbidity and comparing the various categories as tabulated and shown in graphical form on pages 23 to 26.

Of particular interest is the frequency distributions shown for the various types of filtration systems on page 23. In the past, the design engineer and other persons involved in choosing filtration systems have been led to believe by advertisements and articles that diatomaceous earth filters provide for greater clarity than sand filters. Although the differences between the three types of filter systems -- sand, pressure diatomite, and vacuum diatomite -- is not great, the graph on page 23 shows that the sand filter system definitely maintains a clearer pool water.

The main reason some people believe diatomaceous earth filters will necessarily provide clearer water is that the openings in the filter media are considerably smaller than those in sand filters. However, sanitary engineers have known for some time that it is not the mere mechanical straining action of the filter media which removes the suspended materials. As pointed out in an article by O'Melia and Crapps (19) other mechanisms such as sedimentation, inertial impingement and centrifugal collection, Brownian movement, chance contact caused by the convergence of fluid streamlines, diffusion caused by a suspended-particle concentration gradient, van der Waals effects, and electrokinetic effects may all play a part in suspended solids removal. The ability of a sand filter to remove

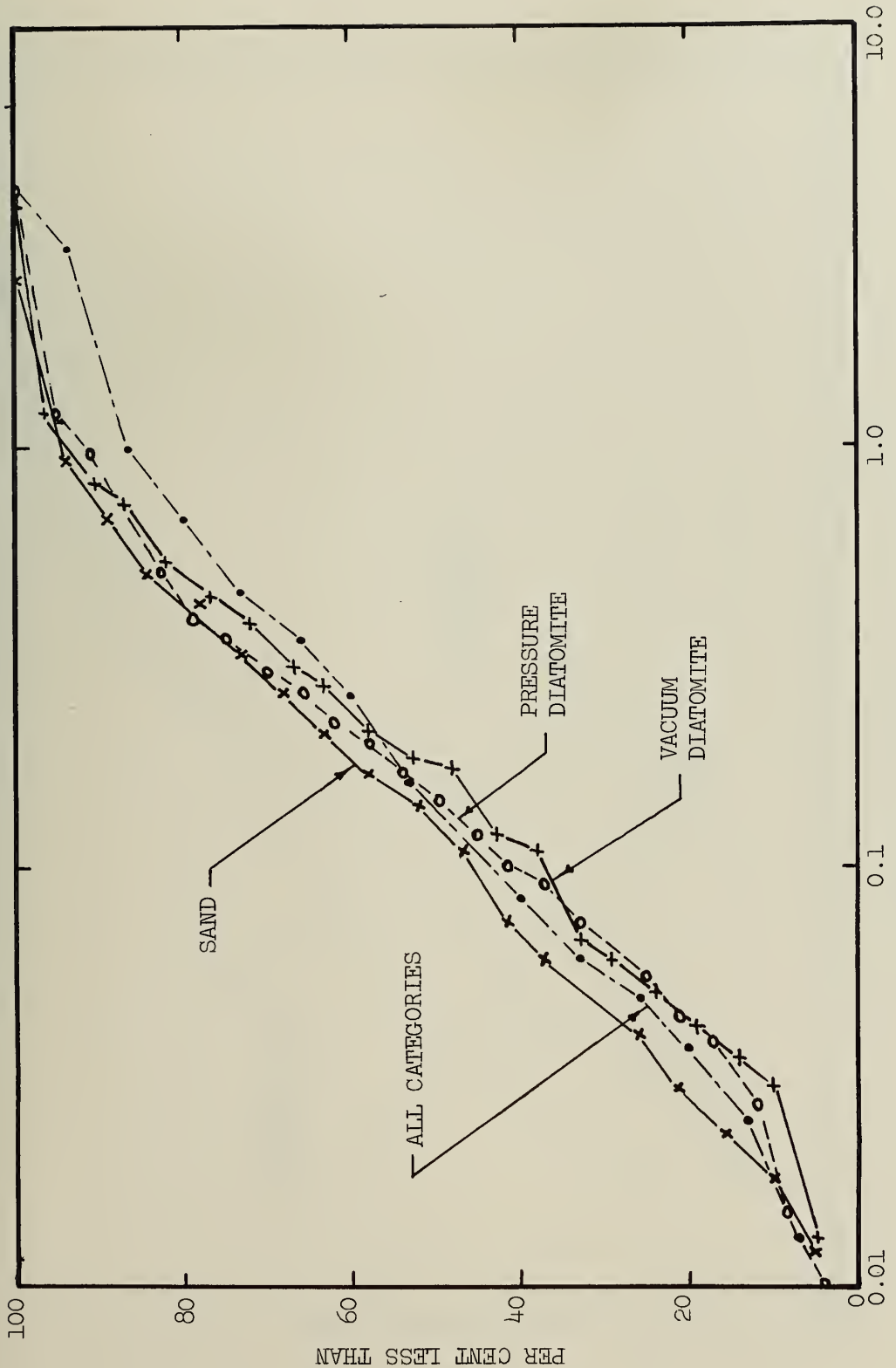

FIGURE 3. ACCUMULATIVE FREQUENCY DISTRIBUTION OF TURBIDITY BY TYPE OF FILTER EXCLUDING WADING POOL SAMPLES.

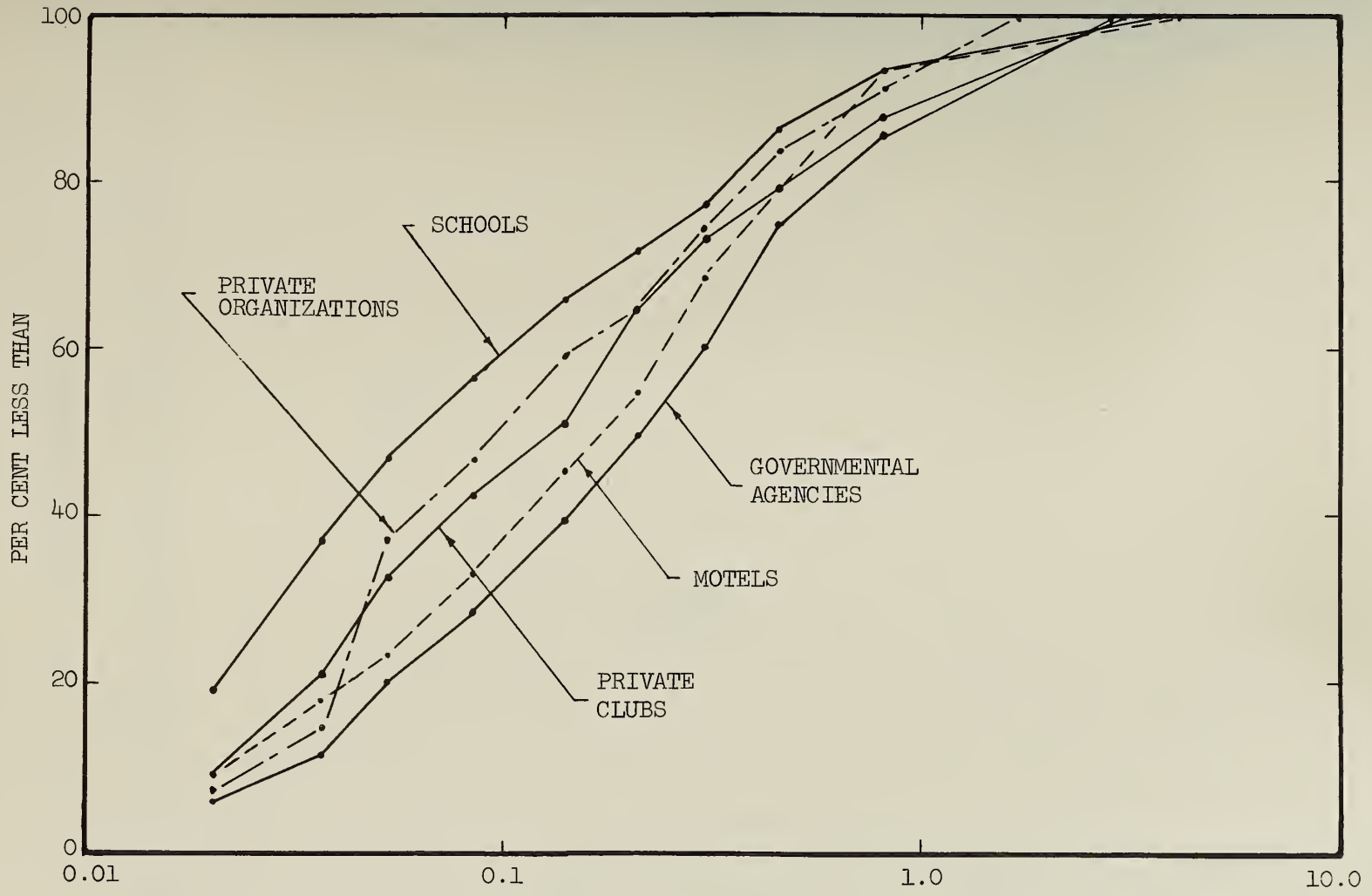

FIGURE 4. ACCUMULATIVE FREQUENCY DISTRIBUTION OF TURBIDITY BY OWNERSHIP EXCLUDING WADING POOL SAMPLES.

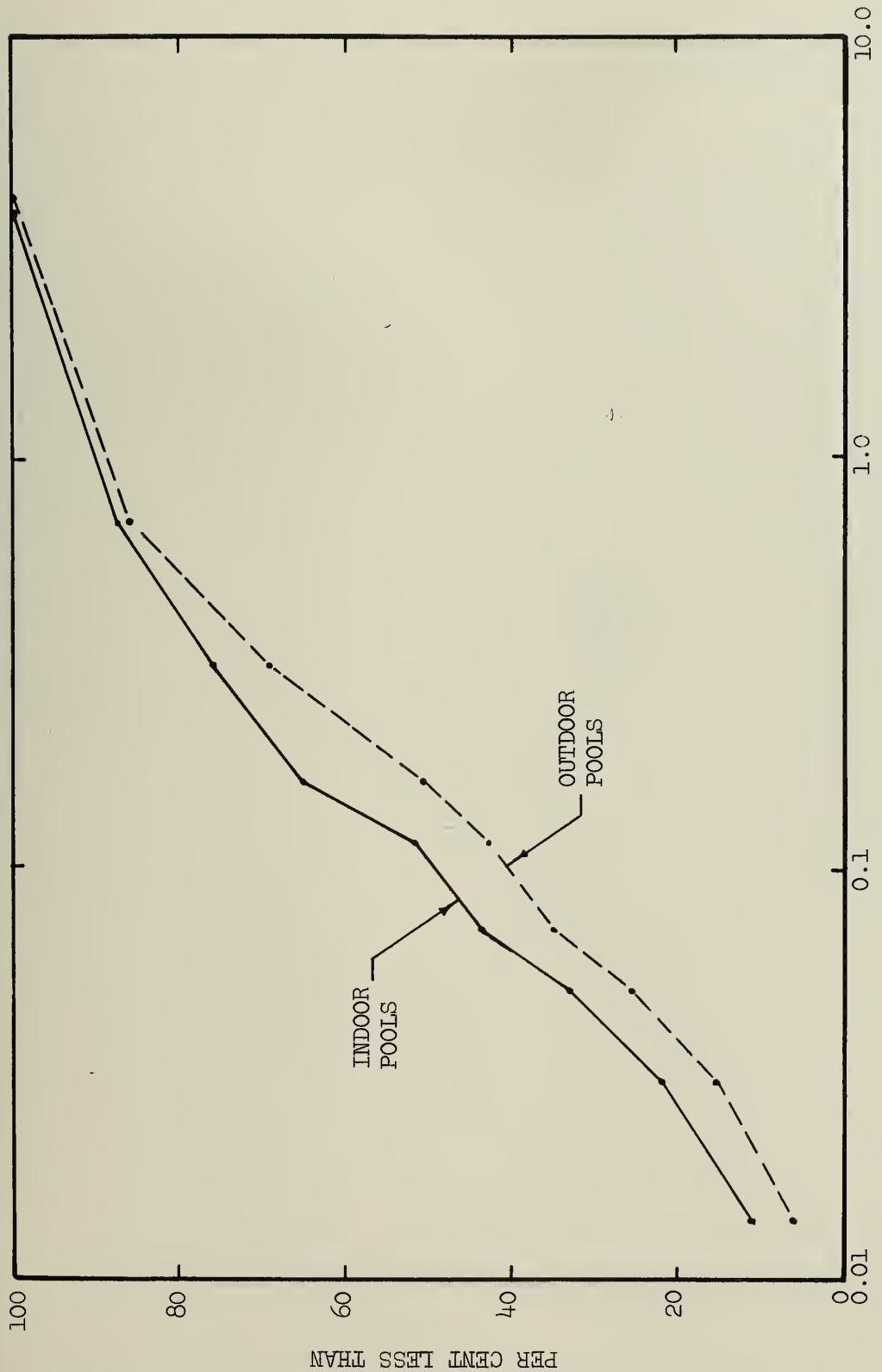

FIGURE 5. ACCUMULATIVE FREQUENCY DISTRIBUTION OF TURBIDITY BY POOL LOCATION - WADING POOL SAMPLES EXCLUDED.

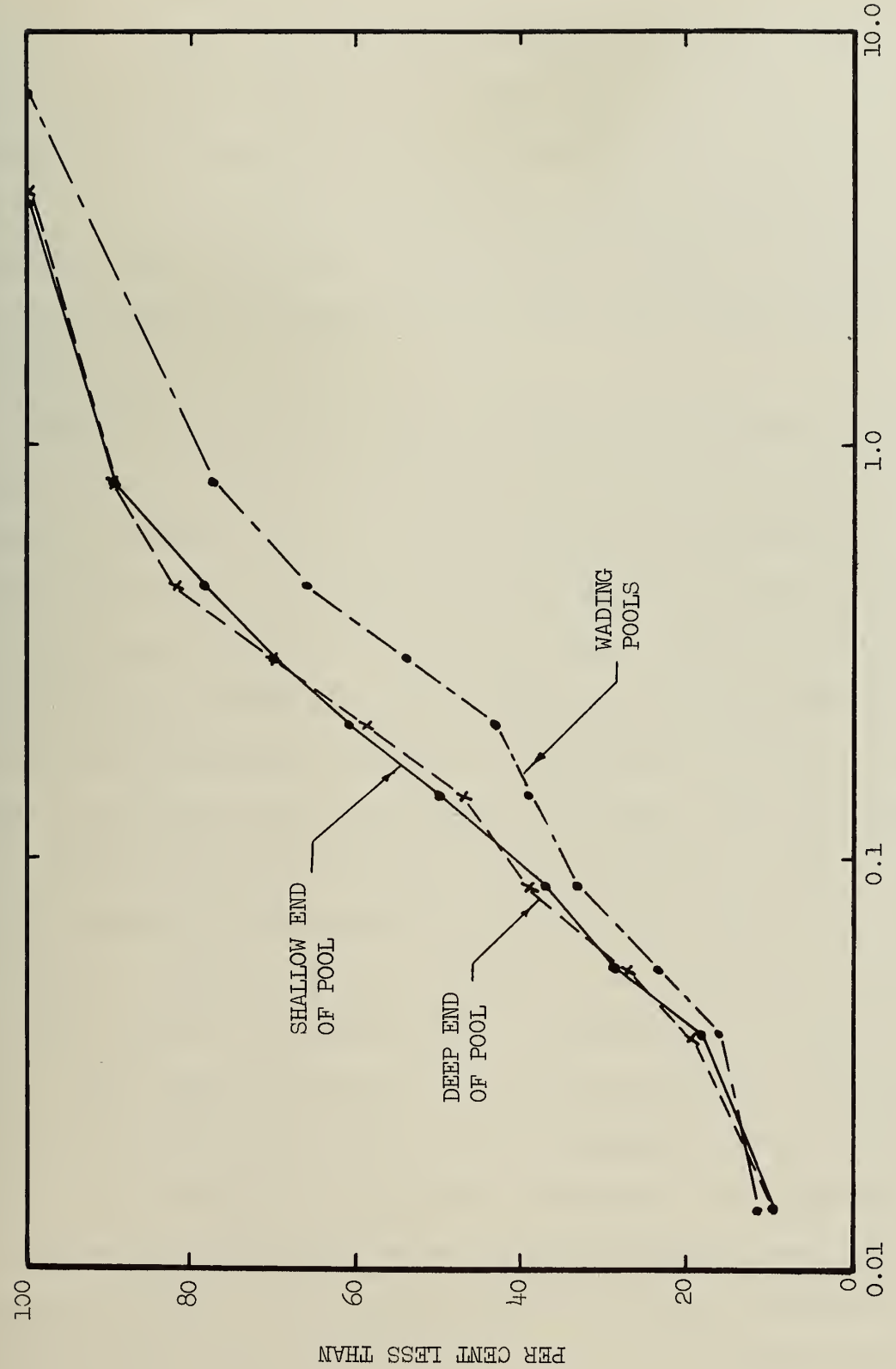

FIGURE 6. ACCUMULATIVE FREQUENCY DISTRIBUTION OF TURBIDITY BY SAMPLE LOCATION.

extremely fine particles was proven by the test procedure reported in Appendix B. None of the particles in the pool water were visible to the naked eye even when subjected to the light in the turbidimeter. However, upon placing the sand filter system back into operation, the removal of particles which were obviously smaller than the pore openings in the sand was quite rapid and efficient. The fast rate of removal is evidenced by the fast decline in turbidity after the filters were placed back into operation.

Many articles which have tried to compare the efficiences of different types of filters have done so more frequently on the basis of head loss, removal of suspended solids, removal of bacteria, and penetration of solids into the filter media and less frequently on the basis of the quality of the filter effluent in terms of turbidity. However, recent work by Conley and Pitman (20,21) and others have utilized the nephelometric method of turbidity measurement to measure the efficiencies of filtration. However, it would appear that the turbidity measurement is the best present means to determine filter efficiency. Disinfection may be relied upon to control bacteria and the bacteria do not contribute significantly to the turbidity of swimming pool waters because of their relatively few numbers. Head loss, removal of suspended solids, and penetration of solids into the filter media, must be considered in the overall evaluation of the filters; however, the filters still must be able to maintain a certain minimum turbidity in the effluent or they cannot be acceptable. The suspended solids test for swimming pool waters is not acceptable primarily due to the fact that the turbidity of the pool water cannot be directly correlated to the suspended solids, and secondly, because the amount of suspended solids in most swimming pool waters is so infinitesimally small so as to be undeterminable by normal suspended solids tests.

One might argue that the information shown graphically on page 23 showing the differences in turbidities in different types of filtration systems is not representative of the individual type of filter system. In fact, it has been hypothesized by Brown (10) that "the ability of a system to keep a pool water clean is a function of main drains, skimmers, inlets, vacuum cleaning, brushing, pipe sizes, friction and head losses, pumps, strainers, flow rates, turnover rates, grades and diatomite sand, or cartridges (sic), square feet of filtering surface, water chemistry and many other design variables". One could easily argue, however, that it is the filter system which can be the primary reason for the clarity of the pool water. Some of the items such as main drains, skimmers, inlets, pipe sizes and friction and head losses contribute primarily to the turnover capacity of the pool. Since all of the pools under study must conform to the Illinois Department of Public Health requirements of a six-hour turnover, these possible intervening factors are minimized considerably. Depending upon the layout of the pool system and other factors, one could easily see that short circuiting might occur in a swimming pool directly from inlet to outlet, particularly at night when no swimmers are in the pool. However, it would appear that when swimmers are in the pool, enough agitation and turbulence of the pool water would exist such that the pool would act as a completely mixed system providing a near perfect six-hour turnover. The almost identical results comparing shallow and deep end pool samples shown graphically on page 26 indicate that the pool water is quite well mixed.

Another group of the factors listed above including skimmers, vacuum cleaning, brushing, and strainers remove only the larger solids which do not contribute significantly to the turbidity of swimming pool water.

The differences in the turbidity frequency distributions for indoor and outdoor pools shown on page 25 are what might be expected. The indoor pools comprised primarily of school pools showed generally clearer waters. One of the reasons for this difference is that indoor pools are not subject to windblown dirt and dust. In addition, it is quite possible that there is better bather control of the patrons of the indoor pools, particularly for the school pools.

As has just been suggested, the graph on page 24 showing the various types of pool ownership shows that the school pools maintain the best of clarity. Since all school pools are indoors, the same reasoning can be applied to this category of pools as was applied to the indoor pools for explaining the lower turbidities. The other categories in order of increasing turbidities are private organizations, private clubs, motels, and government agencies. The category of private organizations includes primarily YMCA and YWCA pools along with a few church pools. Generally speaking, the YMCA and YWCA pools are indoor pools whereas the church pools are outdoors. The larger percentage of indoor pools might again indicate to some degree as to why this particular group of pools has lower turbidities when compared with the other groups. Private organizations consisting primarily of country club pools and other private pools with restricted membership operating on an annual fee basis exhibit the next best group of pools in terms of clarity.

Perhaps one of the reasons for the motel group having relatively high turbidities is the fact that most if not all motel pools have no adjacent bathing preparation facilities. This coupled with the fact that the motel operators must rely on the individual swimmer to shower before coming to the pool areas as well as the ability to track in dirt to the pool area might

contribute to these higher readings. It should also be noted that the bather load in the motel pools is the lowest within the ownership categories with the exception of the school pools. In fact, it is less than half the average bather loading of the governmental agency-owned pools such as the city and park district pools which have the highest turbidities. One might have expected better results from the governmentally owned pools as compared to privately owned pools since there might be less reason to cut corners in operating and maintaining a pool for which operational expenses do not come out of the pocket.

The last frequency distribution has been separated into categories according to the location of pool sampling. As has been mentioned earlier in this report, the usual procedure of pool operators is to provide one sample from both the shallow and deep ends of the pool as well as a sample from a wading pool, if present. The graph on page 26 shows little difference between the shallow and deep samples. For the wading pools, however, the turbidities are considerably higher. Reasons for this have been discussed to a certain extent on pages 18 and 19.

CHAPTER VI.

CONCLUSIONS

On the basis of the investigation reported herein, it is possible to draw some conclusions.

1. For all samples analyzed excluding those from wading pools, the average turbidity was 0.309 Jackson Turbidity Units as determined by the Hach Model 1860 turbidimeter. The standard deviation was 0.460 JTU. The turbidity ranged from 0.003 to 4.1 JTU.

2. Based on the study reported in Appendix B and the statistical analyses in Appendix C, the following ranges of turbidity and their visual descriptions are suggested:

0.000 - 0.099 JTU	Excellent clarity
0.100 - 0.299 JTU	Adequate clarity
0.300 - 0.699 JTU	Noticeably turbid
Greater than 0.700 JTU	Unacceptable

With these guidelines, the allowable turbidity of swimming pool waters might be designated as follows:

> The turbidity should not exceed 0.2 Jackson Turbidity Units as measured by the Hach Model 1860 Turbidimeter 90% of the time while the pool is in use and further that the turbidity not exceed 0.7 JTU by similar measurement while the pool is in use. The time in which the pool is in use shall be considered the time swimmers are in the pool.

3. For the pools equipped with sand filters, the average turbidity was 0.279 JTU. This is markedly better than those equipped with pressure diatomite, 0.313 JTU, or vacuum diatomite, 0.380 JTU.

4. Indoor pools with an average turbidity of 0.271 JTU were generally clearer than outdoor pools which had an average turbidity of 0.321 JTU.

5. In order of most clear to least clear, the ranking of the categories of pool ownership are as follows:

Schools	114 samples averaged 0.245 JTU
Private organizations	54 samples averaged 0.247 JTU
Private clubs	256 samples averaged 0.292 JTU
Motels	150 samples averaged 0.314 JTU
Governmental agencies	178 samples averaged 0.389 JTU

6. Shallow end samples averaged 0.331 JTU as compared to 0.305 JTU for deep end samples. The wading pool samples averaged 0.808 JTU indicating a considerably higher degree of contamination than the main pools. However, since the wading pools are so shallow, the higher turbidities are not significant.

7. No significant correlations can be made between the turbidity and such variables as pH, temperature, number of swimmers, number of swimmers during the twelve hours previous to sample collection, number of swimmers per thousand gallons of pool volume, number of swimmers during the twelve hours previous to sample collection per thousand gallons of pool volume, chlorine residual, coliform bacteria, total bacteria, or streptococci bacteria.

8. The clarity of a swimming pool water is primarily determined by the capabilities or efficiency of its filtration system. The experimentation reported in Appendix B whereby the sand filtration system returned the pool clarity to a near optimum condition in 17.5 hours after 151 hours of by-passing the filters while 711 swimmers used the pool, provides some insight as to possible filtration effectiveness. Even taking into account additional turbidity sources for other pools such as wind blown dust and dirt for outdoor pools, overnight continuous filtration of the pool water should

adequately clear up the water by the next morning if the filtration system is efficient.

Chemical precipitates such as those of iron and alum may not be effectively removed without special attention. However, by oxidizing the iron perhaps with chlorine and by care in addition of alum as to location and quantity, the turbidity from iron and alum hydroxides can be controlled.

CHAPTER VII.

SUGGESTIONS FOR FUTURE WORK

A considerable amount of information could be obtained by several experiments similar to that reported in Appendix B where the turbidity in a pool is allowed to increase to a point where it is unacceptable for safety or aesthetic reasons. In these experiments, consideration should be given to the following:

1. Light measurements should be determined at various depths and locations within the pools.
2. Outdoor and indoor pools should be included not only to determine the differences in the amount of light available, but to determine possible differences in the rates of turbidity increase. Some information might be obtained in regard to the amount of wind blown dust and dirt by obtaining dust fall samples near the outdoor pools. The rate of increase of turbidity as well as the decrease of turbidity after the filters have been placed back into operation should be measured.
3. A considerable number of bacterial samples should be taken to see if turbidity producing solids interfere with the disinfecting action of the chlorine, bromine or iodine.
4. If a new sand filter or a sand filter in which new sand has been placed is available for experimentation, one should study the possible effects of the "ripening" of sand filters. It would appear logical that new, clean sand would not remove turbidity as effectively as sand which may be covered with a

zoogleal slime. This effect may be more pronounced for the low level turbidities encountered in swimming pool water.

5. The comparative effectiveness of filters in removing "artificial" and "natural" pool dirt should be studied and, if possible, the components of an adequate artificial dirt recommended.
6. For bacteriological analyses, it would be preferable to use membrane filters in order to get an actual count of the bacteria.
7. After obtaining information on the rate of increase of turbidity and filter removal efficiencies, filter effluent quality standards could be established in units of turbidity.

Another task emphasized by this study is the need for a standard instrument for determining the turbidity of water and other liquids. In developing such a method or machine, the researcher should keep in mind that the method or machine should be correlated to the ability to actually see through water for it is this ability and not the quantity of scattered light which is desired. Thus a machine which can be easily standardized and which measures the crispness (or haziness) of a standard object through a water sample would be ideal. This, in a way, would be reverting to the Jackson Candle Method except that the reading would be done electronically. A device with an automatic scanning photocell which could electronically perceive a standard image might be possible.

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APPENDIX A

PROCEDURE FOR TURBIDITY ANALYSIS

The Hach Model 1860 Laboratory Turbidimeter is a nephelometer using the principle that light passing through a substance is reflected or scattered by particulate matter suspended in the substance. The light which is reflected at 90° to the light beam is received by the photocells. It was calibrated at the Hach factory by comparison with a suspension of an artificial turbidity standard called Formazin. The Formazin solution turbidity was determined by the Jackson Candle Turbidimeter.

Before each use in the laboratory, the instrument was standardized with a polyacrylic plastic rod into which a special turbidity material had been cast. This standard turbidity material when placed in the turbidimeter reflects an amount of light equal to 49 JTU as compared to the Jackson Candle Turbidity measurement. The turbidity in the rod is made of a completely inert material and does not deteriorate or settle out since it is suspended in a solid.

After standardization of the instrument prior to each use, the turbidity of triple distilled water was determined as a reference point and an additional check. At various times during each set of analyses, the instrument was restandardized and the turbidity of triple distilled water checked in order to insure that the instrument was providing good relative measurements. The turbidity of triple distilled water was usually in the range of 0.005 to 0.015 JTU. There are five scales on the Hach instrument. They are 0 to 1000 JTU, 0 to 100 JTU, 0 to 10 JTU, 0 to 1 JTU, and 0 to 0.2 JTU. For those turbidities in the 0 to 10 JTU range, the results were read to the nearest 0.1 JTU. For those in the 0.0 to 1.0 JTU range, the results were read to the nearest 0.01 JTU and for the 0.0 to 0.2 JTU range, the results were read to the nearest 0.001 JTU. All results were read after the needle showed a steady deflection.

Before each sample was analyzed in the Hach Model 1860 Turbidimeter, the sample cuvette was washed by hand in a strong detergent solution, rinsed in demineralized water and given a final rinse in triple distilled water. The same glass cuvette was used throughout the entire study so that there would be no error due to possible differences in cuvettes. After the final rinse, the exterior of the cuvette was dried with a paper hand towel. It was found that paper towels were preferred over cloth since cloth fibers were left on the exterior of the cuvette. It would have been best to air dry or heat dry the cuvette between samples but because of the extra time needed for this, it was not possible. In addition, the instruction book for the turbidimeter noted that a few smudges on the exterior of the container would not contribute significantly to error in the measurements.

It was necessary to clean the cuvette extremely well between usages not only to eliminate carry-over of turbidity from one sample to another but to minimize the number of air bubbles which stuck to the inside of the cuvette. Most of the samples had a great number of air bubbles after they were poured into the cuvette. However, the washing did not entirely eliminate the bubbles clinging to the inside of the container. It is theorized that some pool water contaminants caused this particular problem. The oils in the swimming pool samples, both the natural body oils as well as the oils from cosmetics and suntan lotions, presumably contributed significantly to this problem. If bubbles did cling to the inside of the cuvette, it was normally possible to loosen them by giving a few quick twists to the cuvette. The bubbles would then rise to the surface. Differences in the readings before and after the twisting of the cuvette indicated possible errors if this procedure was not carried out. This was particularly noticeable in the lower turbidity ranges.

Samples were obtained from the regional laboratory of the State Health Department on a weekly or more often basis, depending upon the number of samples received by the laboratory. These samples were refrigerated at the Health Department Laboratory and after transfer to the Health Service Laboratory. Turbidity analyses were performed at least once weekly during the swimming pool season. It was necessary to allow the samples to stand at room temperature for approximately one hour before analysis. This was necessary because condensation formed on the outside of the sample cuvette and interferred with the turbidity readings.

It was found that plastic prescription containers normally used by pharmacists for pills were quite satisfactory for sample containers. These plastic containers could be washed rather easily and re-used. A laboratory marking pencil was used to number the samples at the Health Department Laboratory. After each use of the plastic containers, they were washed in a strong detergent solution and rinsed in tap water, demineralized water, and triple distilled water in that order. After washing they were allowed to air dry before re-use.

The precision of the instrument appears to be adequate. A suspension of clay was diluted with triple distilled water to a turbidity fairly close to the average of all samples analyzed for this paper. Ten aliquots analyzed from this sample were read to the nearest 0.01 JTU. They ranged from 0.44 to 0.47 JTU with an average of 0.457 JTU and a standard deviation of 0.0078. This suspension was diluted further and an additional ten aliquots analyzed. These results were read to the nearest 0.001 JTU and ranged from 0.065 to 0.090 JTU with an average of 0.0772 JTU and a standard deviation of 0.0084. Ten aliquots of triple distilled water were analyzed and read to the nearest 0.001 JTU. The results ranged from 0.008 to 0.013 with an average of 0.0108 JTU and a standard deviation of 0.0014.

As has been discussed in Chapter III, the results of turbidity analyses using a nephelometer such as the one used for this research may not be comparable to those results obtained by other means. This is primarily due to the unreliability of "standard solutions" used for calibration and/or standardization. In order to get some idea of the relationship between the results obtained from this work as compared to results from the Jackson Candle Turbidimeter, suspensions of clay and diatomaceous earth were analyzed by both methods.

The turbidities below 25 JTU which could not be measured directly by the Jackson Turbidimeter were calculated from the dilution used. The results of these analyses are shown graphically on pages 43 and 44. The differences between the Hach instrument and the Jackson Turbidimeter range from a ratio of approximately 1:2 to about 1:7 depending upon the amount of turbidity present and the type of suspension material used. Thus, the turbidities reported in this paper should not be compared directly with results obtained by other means.

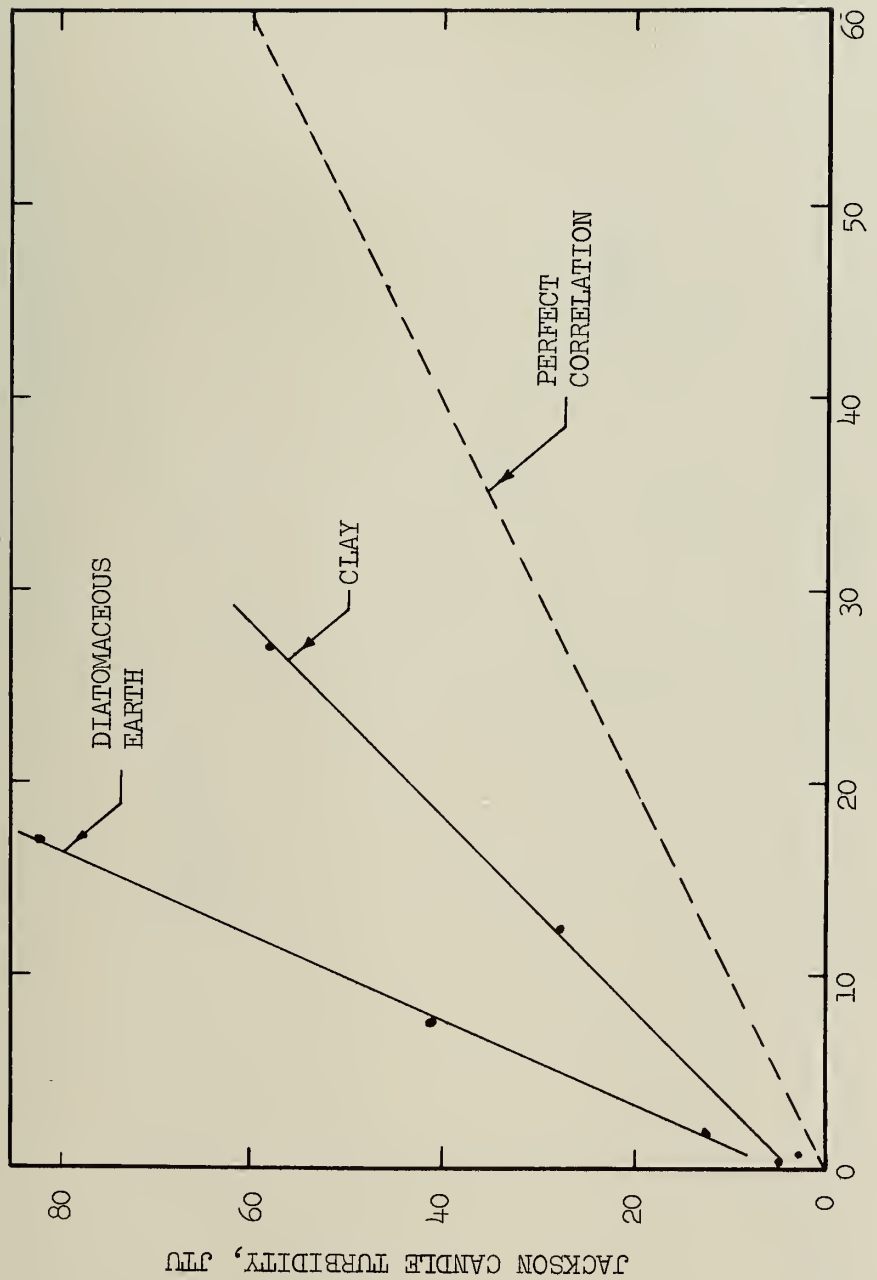

FIGURE 7. COMPARISON OF HACH AND JACKSON CANDLE TURBIDIMETERS FOR LOW TURBIDITIES.

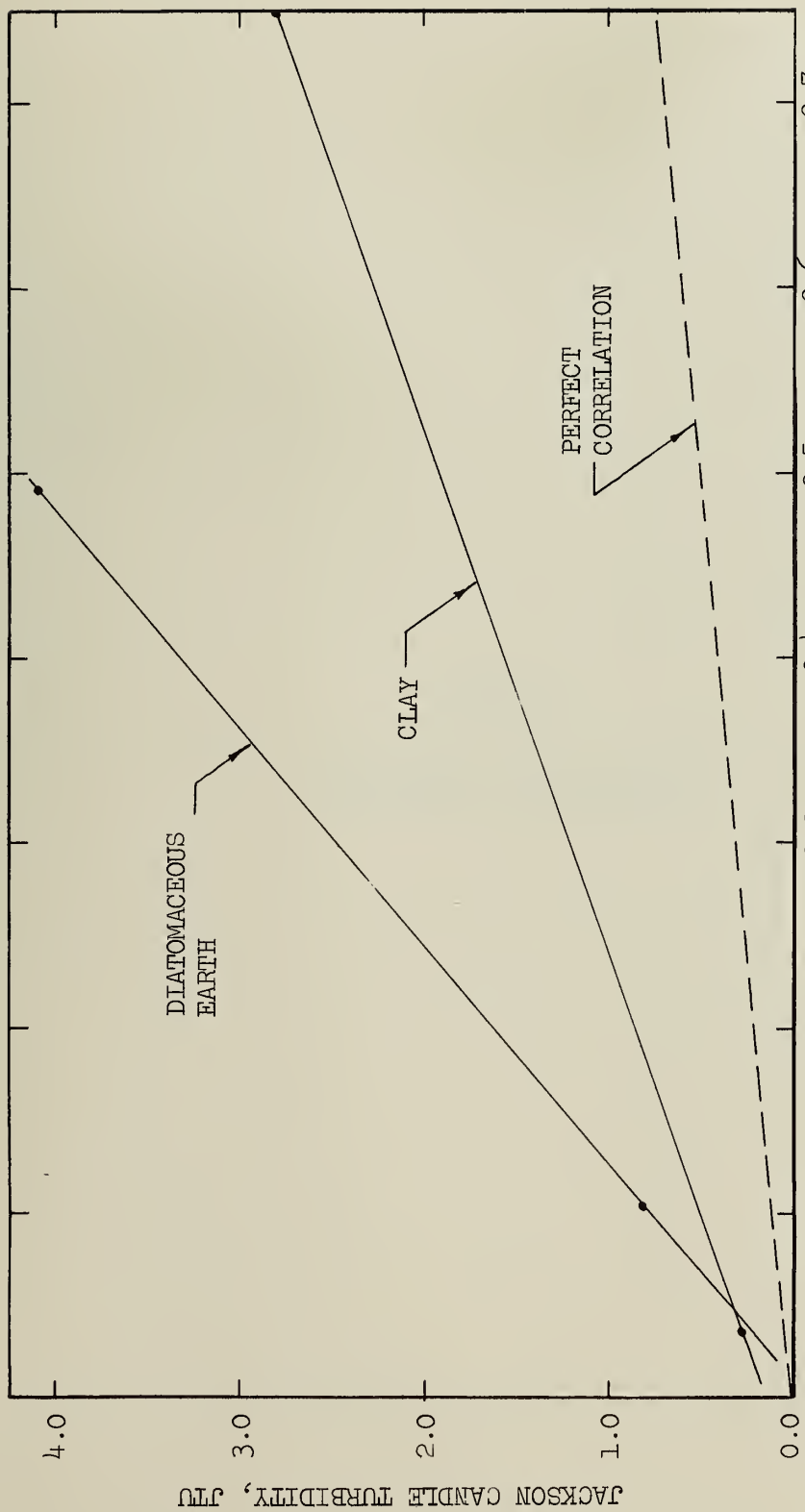

FIGURE 8. COMPARISON OF HACH AND JACKSON CANDLE TURBIDIMETERS FOR LOW TURBIDITIES.

APPENDIX B

COMPARISON OF VISUAL WATER APPEARANCE AND TURBIDITY

Only one reference (3) could be found which defines the appearance of a swimming pool in terms of turbidity. Jackson assumes that 1.0 JTU is satisfactory though his method of determination is not revealed. Limits for maximum turbidity units in water for other uses have been defined. The 1962 United States Public Health Service Drinking Water Standards (22) specify that the turbidity shall not exceed 5 JTU for a potable water supply. Bean (23) has proposed a much stricter limit of 0.1 JTU for ideal drinking water. Many of the recommended limits of turbidity for the various industrial uses of water (24) are in the range of 1 to 25 with the exception of the textile industries and in particular those making cotton (Callaway Mills) and nitrocellulose which require a turbidity of 0.3 - 0.5 Jackson Turbidity Units.

It was decided to allow the turbidity in a University swimming pool to increase to a point where it was close to being unsafe for use. In order to do this, it was necessary to bypass the filtration system during the test period. Thus, the turbidity was natural (from the bathers) and not artificial such as clay which might have been used to increase the turbidity. It was of course necessary to continue chlorination of the pool water during the test in order to insure that water-borne diseases would not be transmitted. Not only did this test provide a means by which visual observations and corresponding turbidimeter determinations could be related, but it also offered a chance to determine the rate at which the filtration system cleared up the water after the filters were returned to operation. In addition, it was possible to compare the capabilities of the two previously accepted methods for determining pool water clarity. The first of these standards uses the six-inch black disc as provided for in the

American Public Health Association Regulations as well as in a number of state standards. This method suggests that the water is clear if:

> A black disc, 6 inches in diameter, on a white field, when placed on the bottom of the pool, at the deepest point, is clearly visible from the sidewalks of the pool at all distances up to 10 yards, measured from a line drawn across the pool to the disc.

The other method of determining the pool water clarity is that suggested by the National Swimming Pool Institute. This method uses a two-inch disc with alternate black and red quadrants. The test specifies that one should be able not only to see the disc through 15 feet of water, but the colors should be distinguishable.

Permission was obtained to carry out the experiments at the University of Illinois Women's Swimming Pool. The pool is 75 feet by 24 feet in plan with a capacity of 68,000 gallons. Depth ranges from 3 1/2 feet to 8 1/2 feet. The filters are conventional pressure sand filters operating at a filtration rate of three gallons per minute per square foot of filter area and the water is recirculated to provide a six hour turnover.

It was decided that the following steps would be taken:

1. The filters would be bypassed and the turbidity allowed to increase in the swimming pool.
2. Daily samples would be taken from the swimming pool for turbidity analyses.
3. Daily determinations would be made using the two disc methods for pool water clarity.
4. Daily visual observations would be recorded.
5. Comments from operational and supervisory personnel would be incorporated into the report, including personal estimates as to the degree of cloudiness of the pool, aesthetic

acceptability of the pool water, and the ability to conduct classes safely.

When this project was in its planning stages, it was thought that the amount of light available in the pool room at and beneath its surface would determine to a great extent the ability of one to see the discs at the bottom of the pool. For this reason, an attempt was made to determine the amount of light as measured in foot-candles at the pool surface and at various points beneath the pool surface. It was found, however, that the amount of light available at the pool surface was only 10 foot-candles and that the light decreased significantly even at a depth of only 2 feet. Since the light meter used for this determination could not be considered accurate at less than five foot-candles, this portion of the experiment was eliminated. It is still believed that such determinations made with a low range light meter beneath the pool surface would add significant information to future studies.

Due to the Tyndall effect, it may be that the water would appear to be more cloudy at lower turbidities if more light was available. This was demonstrated at pool side by shining a portable lantern into the water. The pathway of the light was pronounced by the light striking the particles suspended in the pool water providing a stream of cloudy water in the pool which otherwise appeared to be relatively clear. This same phenomenon is sometimes produced out by underwater lights.

Most of the samples for turbidity were obtained in the morning before the pool was used. A grab sample of slightly greater than 100 ml. was taken from each side of the pool. The composited sample was then taken directly to the laboratory and analyzed for turbidity. Ten samples were analyzed from each composite with the average of the ten taken as the daily

turbidity. The turbidities were then plotted versus the number of days the pool was in operation and versus the number of swimmers using the pool facilities. These graphs are included on pages 50 and 51.

On the first day of the test before the filters were bypassed the turbidity was 0.022 JTU. Both the black six-inch disc and the black and red two-inch disc were visible and the colors were distinguishable on the two-inch disc. The water had excellent clarity and one could distinguish quite well the racing lanes in the bottom of the pool.

At the end of 24 hours, the turbidity had risen to 0.178 after 199 swimmers had used the pool. Both discs were visible and the colors distinguishable on the two-inch disc. There appeared to be no change in the visual clarity of the pool water though both the operator and the instructor in charge of the pool said they could tell the difference in the turbidity.

After 48 hours, the turbidity had risen to 0.260 JTU after another 84 swimmers had used the pool. At this point there was a slight haziness to the pool water. However, it appeared that the clarity was adequate.

After 72 hours of operation and another 244 swimmers had used the pool, the turbidity increased to 0.427. It was at this time that one could say that the pool water appeared to be fairly hazy or turbid. The small disc was barely visible at 30 feet horizontal from the disc and the larger six-inch disc was still noticeable but considerably less so than on the previous day. The colors on the small disc were not distinguishable through 15 feet of water and were barely visible through 8.5 feet of water. It was at this point that the instructor stated she was somewhat wary about the condition of the pool. The pool was not aesthetically acceptable even though it had passed the American Public Health Association test.

After 96 hours of operation and another 76 swimmers had been in the pool, the turbidity increased to 0.463. Again, colors on the small disc

FIGURE 9. INCREASES IN TURBIDITY VERSUS TIME.

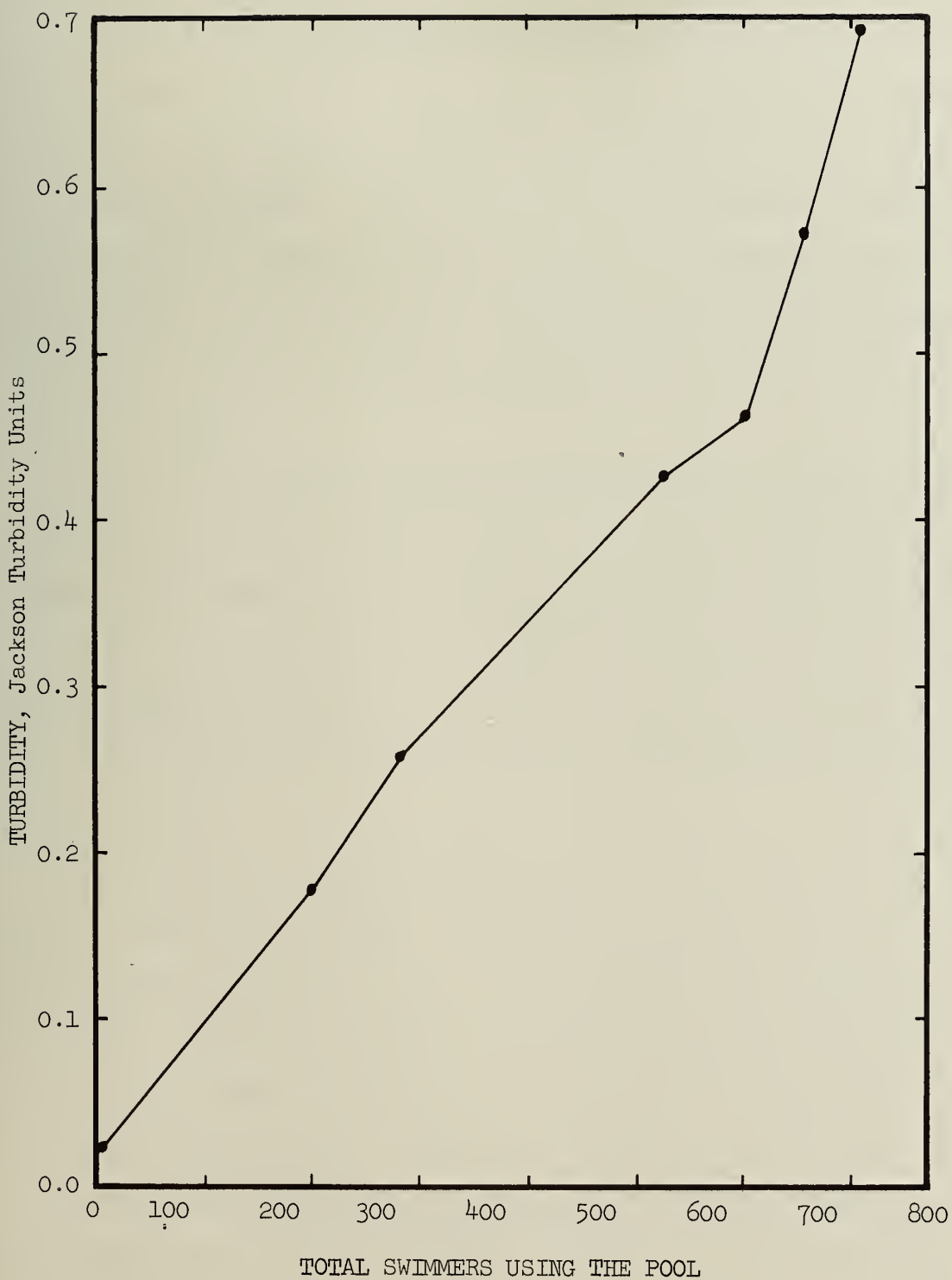

FIGURE 10. INCREASES IN TURBIDITY VERSUS NUMBER OF SWIMMERS.

were barely distinguishable through 8.5 feet of water. The six-inch disc was still visible at 30 feet horizontally from the disc but one had to search for the small disc.

After 144 hours and another 55 persons had used the pool, the turbidity had increased to 0.574 JTU. Seven hours later or after a total of 151 hours of operation and another 53 persons had used the pool, the turbidity increased to 0.696 JTU. It was at this time the instructor indicated that the pool was too turbid to continue using the pool. Some potential swimmers had refused to swim in the pool on the previous day which was Sunday. The complaint or reason for not using the pool given by those persons was that it was too cloudy.

The six-inch black disc was not noticeable after 151 hours. However, it should be noted that there was still a slight wave action due to swimmers just leaving the pool which interfered with sighting the disc. All of the other observations for sighting the disc were done in the morning before swimmers had entered the pool so that wave action did not interfere. The colors on the two-inch disc were still nondistinguishable through 15 feet of water.

The filters were placed back into operation at 2:00 p.m. after 151 hours of bypassing the filters. By 5:00 p.m. of the same day, the turbidity had decreased from 0.696 to 0.538. This decrease in the turbidity of the pool water took place even though an additional 23 swimmers had used the pool and even though theoretically only one-half of the pool water had been re-circulated and filtered. By the next morning after a total of 17.5 hours of filtration the turbidity had decreased to 0.055 JTU. Thus the filters returned the pool water to a clarity comparable to that before the experimentation was started. One could say that the turbidity added during 151

hours of nonfiltration was removed in 17.5 hours or that this particular filtering system was apparently able to remove the turbidity approximately 8.5 times as fast as it was being introduced to the pool.

Thus it would appear that this particular filtration system was overdesigned. It is obvious, however, that some factor of safety should be built into each filtration system so that adequate clarity could be maintained during periods of high bather loadings and subsequent increased addition of suspended materials. In addition, some consideration should be given to an additional factor of safety for those pools which do not receive a high degree of operation and maintenance.

It has been suggested by Brown (10) that an artificial pool dirt composed of soluble machine cutting oil, baby powder talc, and fine cellulose fiber be mixed in a given pool to provide 10 ppm (or JTU) of turbidity. He suggests that the number of hours required to clarify the water to the point where the American Public Health Association six inch black disc is seen be determined. Thus, if it takes 110 hours, the rating is 110 and if it takes 14 hours, the rating is 14. This might give some idea of the efficiencies of the various filters on the market. However, it should be noted that the installation and construction of these filters might vary such that they might not give comparable performances in actual operation. A better solution might be the inclusion of a performance standard in the plans and specifications for a swimming pool. However, additional study is needed before such a standard can be suggested. First of all, it would be necessary after a pool filter system is installed to test the swimming pool prior to use. This would necessitate the use of an artificial pool dirt as suggested above. Before this is done, tests should be made comparing turbidity removal efficiencies using artificial and natural pool dirt. In

addition, it would be necessary to determine the average or maximum rate at which the turbidity is introduced into the pool. Once such data are obtained, it would be possible to determine or specify a maximum number of hours during which the pool water should be returned to a specific turbidity. Also, it would seem unnecessary to add artificial turbidity to a pool water for a performance test above that point which is considered acceptable. In other words, if the maximum allowable turbidity in a swimming pool was set at 0.7 JTU, it would seem unwise to provide an artificial turbidity greater than 0.7 JTU since these higher turbidities should not be encountered in practice.

Based on these observations, the six-inch black disc was of no help in determining the acceptability of the pool water clarity since the pool water became so cloudy some swimmers refused to swim before the black disc was no longer visible. Colors on the two-inch disc became indistinguishable at an earlier time during the test though the turbidity had built up to a considerable extent by that time. Though these discs may be of some help in determining the clarity of the pool water, they obviously cannot be relied upon to detect significant changes in turbidity.

Based on this experiment, the following ranges of turbidity and corresponding remarks about the visual clarity are in order:

0.000 - 0.099 JTU	Excellent Clarity
0.1 - 0.299 JTU	Satisfactory clarity. However, experienced personnel accustomed to good clarity could notice the difference
0.3 - 0.699 JTU	Aesthetically objectionable
0.7 JTU and over	Unacceptable - Definite hazards involved in seeing the swimmers

The limit of 0.7 JTU suggested as being a maximum allowable turbidity is somewhat justified by checking the operational reports from other swimming pools. Information to be provided by the operator on the bacteriological report sheet includes a blank for the water appearance. Those report sheets on which the water appearance was noted to be turbid, cloudy or hazy were separated from the others. These 24 samples averaged 0.769 JTU. In other words, all the pools included in the main study which were said to be cloudy or turbid had an average turbidity of 0.769 JTU. This would tend to justify the upper limit or maximum allowable turbidity of 0.7 JTU as measured by the Hach Model 1860 Turbidimeter.

APPENDIX C

STATISTICAL ANALYSES OF VARIABLES

TABLE 3

STATISTICAL ANALYSES OF VARIABLES

All Categories

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.344	0.586	809	1.000	.468
Turbidity Load Factor	0.909	2.968	642	.468	1.000
pH	7.49	.382	809	-.070	-.119
Temperature ^{o}F.	78.3	4.78	603	-.019	-.031
No. of Swimmers	74.5	199.4	715	-.0008	-.073
No. Swim/12 hr	148.2	315.8	652	.024	-.096
No. Swim/1000 gal	.357	.499	705	.109	-.121
No. Swim/12 hr/1000 gal	1.003	1.940	644	.254	-.101
Chlorine Residual	1.047	.581	714	-.143	-.124
Coliform	1.102*	.696*	811	.098	-.012
Total Bacteria	144.8	673.7	248	.049	-.014
Streptococci	1.022*	.1911*	811	.023	-.017
Pool Size	171,002	196,009	801	-.012	-.014

TABLE 4

Type of Filter, Part 1 -- Sand

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.278	.406	394	1.000	.332
Turbidity Load Factor	.876	3.005	325	.332	1.000
pH	7.48	.328	392	.164	.061
Temperature ^{o}F.	78.4	5.08	310	-.052	-.007
No. of Swimmers	29.7	49.9	365	.008	-.097
No. Swim/12 hr	76.3	104.0	325	.047	-.131
No. Swim/1000 gal	.256	.308	365	.090	-.122
No. Swim/12 hr/1000 gal	.774	1.054	325	.155	-.128
Chlorine Residual	1.016	.558	349	-.212	-.106
Coliform	1.076*	.613*	394	.244	.003
Total Bacteria	84.5	456.3	131	.243	.040
Streptococci	1.025*	.200*	394	.009	-.024
Pool Size	107,271	63,093	394	-.149	.036

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 5

STATISTICAL ANALYSES OF VARIABLES

Type of Filter, Part 2 -- Pressure Diatomite

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.315	.464	248	1.000	.481
Turbidity Load Factor	.750	1.868	203	.481	1.000
pH	7.46	.382	249	-.115	-.087
Temperature ^{o}F.	78.2	4.62	162	.002	-.213
No. of Swimmers	75.6	130.3	226	.191	-.118
No. Swim/12 hr	138.0	239.4	204	.190	-.139
No. Swim/1000 gal	.394	.506	226	.191	-.162
No. Swim/12 hr/1000 gal	.883	.938	204	.206	-.203
Chlorine Residual	1.035	.573	210	-.035	.073
Coliform	1.088*	.628*	249	.081	-.012
Total Bacteria	349.5	1154.0	61	.023	.055
Streptococci	1.012*	.141*	249	.082	.029
Pool Size	158,209	211,577	249	.086	-.118

TABLE 6

Type of Filter, Part 3 -- Vacuum Diatomite

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.521	.846	141	1.000	.619
Turbidity Load Factor	1.334	4.37	105	.619	1.000
pH	7.61	.501	142	-.275	-.671
Temperature ^{o}F.	79.0	3.44	112	-.034	.112
No. of Swimmers	222.2	439.2	106	.145	-.126
No. Swim/12 hr	381.7	629.2	106	-.126	-.154
No. Swim/1000 gal	.636	.819	106	-.026	-.163
No. Swim/12 hr/1000 gal	1.990	4.087	106	.268	-.121
Chlorine Residual	1.185	.667	130	-.305	-.233
Coliform	1.113*	.725*	142	.038	-.041
Total Bacteria	67.8	183.2	52	.081	-.018
Streptococci	1.035*	.250*	142	.012	-.036
Pool Size	294,885	224,217	142	-.197	-.084

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 7

STATISTICAL ANALYSES OF VARIABLES

Pool Location, Part 1 -- Indoor Pools

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.271	.484	184	1.000	.322
Turbidity Load Factor	.748	1.86	172	.322	1.000
pH	7.55	.270	184	.128	-.056
Temperature °F.	81.4	3.13	146	-.231	-.105
No. of Swimmers	18.5	14.1	182	.113	-.184
No. Swim/12 hr	42.7	36.5	172	.434	-.120
No. Swim/1000 gal	.231	.199	182	.200	-.179
No. Swim/12 hr/1000 gal	.549	.502	172	.429	-.151
Chlorine Residual	1.155	.509	184	-.210	-.095
Coliform	1.081*	.634*	184	.309	.020
Total Bacteria	254.0	1015.4	78	.004	-.036
Streptocci	1.021*	.179*	184	.058	-.033
Pool Size	95,169	54,286	184	-.094	.134

TABLE 8

Pool Location, Part 2 -- Outdoor Pools

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.365	.612	625	1.000	.498
Turbidity Load Factor	.968	3.27	470	.498	1.000
pH	7.47	.408	625	-.096	-.127
Temperature °F.	77.4	4.81	457	.041	-.019
No. of Swimmers	93.6	227.8	533	-.018	-.082
No. Swim/12 hr	186.0	360.1	480	-.001	-.109
No. Swim/1000 gal	.402	.561	523	-.093	-.129
No. Swim/12 hr/1000 gal	1.168	2.224	472	.252	-.108
Chlorine Residual	1.009	.599	530	-.118	-.128
Coliform	1.108*	.713*	627	.054	-.019
Total Bacteria	94.7	430.8	170	.123	-.045
Streptococci	1.022*	.194*	627	.016	-.014
Pool Size	193,617	316,311	617	-.022	-.032

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 9

STATISTICAL ANALYSES OF VARIABLES

Ownership, Part 1 -- Governmental Agency

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.397	.490	209	1.000	.437
Turbidity Load Factor	.756	1.782	156	.437	1.000
pH	7.46	.449	209	-.029	.031
Temperature ^{o}F.	77.5	5.20	163	.049	.053
No. of Swimmers	240.3	352.2	172	-.032	-.175
No. Swim/12 hr	436.9	536.0	158	-.025	-.224
No. Swim/1000 gal	.729	.772	172	.115	-.239
No. Swim/12 hr/1000 gal	1.425	1.313	158	.092	-.290
Chlorine Residual	1.172	.634	200	-.030	-.021
Coliform	1.170*	.899*	211	.060	-.029
Total Bacteria	37.1	138.2	61	-.088	-.081
Streptococci	1.028*	.237*	211	.056	-.035
Pool Size	397,683	257,514	211	-.067	.037

TABLE 10

Ownership, Part 2 -- Motels

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.314	.491	150	1.000	.511
Turbidity Load Factor	1.146	2.578	114	.511	1.000
pH	7.63	.385	150	.086	.043
Temperature ^{o}F.	76.4	.559	94	-.163	-.109
No. of Swimmers	6.32	6.87	134	.050	-.216
No. Swim/12 hr	26.0	27.2	114	.262	-.227
No. Swim/1000 gal	.149	.160	134	.0006	-.234
No. Swim/12 hr/1000 gal	.616	.719	114	.189	-.214
Chlorine Residual	.863	.673	127	-.125	-.038
Coliform	1.200*	.983*	150	.289	.007
Total Bacteria	404.1	899.6	22	.804	-.189
Streptococci	1.020*	.140*	150	.129	-.044
Pool Size	43,131	11,982	150	.078	-.005

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 11

STATISTICAL ANALYSES OF VARIABLES

Ownership, Part 3 -- Schools

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.245	.512	114	1.000	.321
Turbidity Load Factor	.837	2.272	112	.321	1.000
pH	7.51	.248	114	.118	-.062
Temperature ^{o}F.	81.4	1.887	96	-.134	-.152
No. of Swimmers	18.7	13.6	114	.185	-.253
No. Swim/12 hr	39.0	34.6	112	.404	-.168
No. Swim/1000 gal	.198	.162	114	.372	-.199
No. Swim/12 hr/1000 gal	.447	.471	112	.491	-.130
Chlorine Residual	1.133	.452	114	-.261	-.065
Coliform	1.000*	0.000*	114	.000	.000
Total Bacteria	39.3	143.3	60	.456	-.071
Streptococci	1.017*	.187*	114	-.042	-.033
Pool Size	107,531	46,435	114	-.260	.074

TABLE 12

Ownership, Part 4 -- Private Clubs

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.379	.738	282	1.000	.515
Turbidity Load Factor	1.021	4.128	224	.515	1.000
pH	7.43	.366	282	-.171	-.258
Temperature ^{o}F.	78.1	4.31	218	.078	-.021
No. of Swimmers	32.6	59.3	247	-.098	-.107
No. Swim/12 hr	78.4	90.7	232	-.067	-.145
No. Swim/1000 gal	.291	.357	237	.091	-.113
No. Swim/12 hr/1000 gal	1.193	2.96	224	.300	-.072
Chlorine Residual	1.000	.524	223	-.226	-.220
Coliform	1.060*	.513*	282	.044	-.014
Total Bacteria	217.6	960.2	89	.010	.325
Streptococci	1.025*	.196*	282	-.009	-.005
Pool Size	114,824	67,127	272	-.270	-.023

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 13

STATISTICAL ANALYSES OF VARIABLES

Ownership, Part 5 -- Private Organizations

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.247	.350	54	1.000	.505
Turbidity Load Factor	.349	.390	36	.505	1.000
pH	7.52	.322	54	-.121	.129
Temperature °F.	81.1	3.94	32	-.025	-.021
No. of Swimmers	18.8	15.5	48	.086	-.076
No. Swim/12 hr	57.0	49.8	36	.245	.383
No. Swim/1000 gal	.310	.259	48	.099	-.087
No. Swim/12 hr/1000 gal	.924	.783	36	.299	-.385
Chlorine Residual	1.028	.475	50	-.064	-.264
Coliform	1.000*	0.000*	54	.000	.000
Total Bacteria	189.9	749.4	16	-.092	-.303
Streptococci	1.000*	0.000*	54	.000	.000
Pool Size	60,207	13,764	54	-.149	.175

TABLE 14

Sample Location, Part 1 -- Shallow End of Pool

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.331	.480	346	1.000	.350
Turbidity Load Factor	.743	1.794	293	.350	1.000
pH	7.48	.330	345	.058	.032
Temperature °F.	78.7	4.68	257	.005	-.013
No. of Swimmers	80.3	208.3	325	.072	-.080
No. Swim/12 hr	153.9	328.7	295	.139	-.106
No. Swim/1000 gal	.371	.509	323	.145	-.148
No. Swim/12 hr/1000 gal	.916	1.190	293	.205	-.171
Chlorine Residual	1.015	.543	316	-.116	-.035
Coliform	1.109*	.721*	346	.115	-.022
Total Bacteria	184.1	754.4	96	.017	-.040
Streptococci	1.011*	.131*	346	.066	-.029
Pool Size	161,430	189,515	344	.058	.068

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 15

STATISTICAL ANALYSES OF VARIABLES

Sample Location, Part 2 -- Deep End of Pool

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.305	.461	342	1.000	.462
Turbidity Load Factor	.807	1.888	290	.462	1.000
pH	7.48	.334	343	.011	.038
Temperature ^{o}F.	78.6	4.72	258	-.048	-.116
No. of Swimmers	79.6	208.9	323	-.024	-.107
No. Swim/12 hr	152.3	328.5	296	-.011	-.131
No. Swim/1000 gal	.371	.513	319	.095	-.167
No. Swim/12 hr/1000 gal	.845	.923	292	.152	-.218
Chlorine Residual	1.007	.532	312	-.138	-.069
Coliform	1.104**	.708**	344	.150	-.009
Total Bacteria	121.3	649.8	97	.050	.008
Streptococci	1.023**	.200**	344	-.008	-.031
Pool Size	157,670	183,151	340	-.067	-.047

TABLE 16

Sample Location, Part 3 -- Wading Pools

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.808	1.37	57	1.000	*
Turbidity Load Factor	*	*	*	*	*
pH	7.65	.709	57	-.417	*
Temperature ^{o}F.	*	*	*	*	*
No. of Swimmers	*	*	*	*	*
No. Swim/12 hr	*	*	*	*	*
No. Swim/1000 gal	*	*	*	*	*
No. Swim/12 hr/1000 gal	*	*	*	*	*
Chlorine Residual	1.406	.824	49	-.352	*
Coliform	1.087**	.662**	57	-.020	*
Total Bacteria	11.4	25.4	32	-.075	*
Streptococci	1.035**	.265**	57	-.020	*
Pool Size	*	*	*	*	*

* Information not available for wading pools.

** Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 17

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

All Categories

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.309	.460	752	1.000	.412
Turbidity Load Factor	.743	1.79	621	.412	1.000
pH	7.48	.343	752	.045	.035
Temperature °F.	78.4	4.88	559	-.023	-.041
No. of Swimmers	76.8	202.	692	.026	-.089
No. Swim/12 hr	152.	320.	631	.063	-.117
No. Swim/1000 gal	.361	.499	684	.121	-.150
No. Swim/12 hr/1000 gal	.895	1.07	623	.176	-.189
Chlorine Residual	1.02	0.55	665	-.153	-.066
Coliform	1.103*	.699*	754	.140	-.007
Total Bacteria	3.29	14.39	216	.101	-.015
Streptococci	1.021*	.184*	754	.039	-.017
Pool Size	155,590	180,000	746	-.0001	.009

TABLE 18

Type of Filter, Part 1 -- Sand

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.279	.406	383	1.000	.376
Turbidity Load Factor	.730	1.670	319	.376	1.000
pH	7.48	.33	381	.158	.065
Temperature °F.	78.4	5.14	300	-.049	-.005
No. of Swimmers	30.2	50.2	358	.007	-.129
No. Swim/12 hr	77.3	104.6	319	.051	-.178
No. Swim/1000 gal	.260	.394	358	.091	-.154
No. Swim/12 hr/1000 gal	.785	1.060	319	.161	-.170
Chlorine Residual	1.016	.561	342	-.203	-.064
Coliform	1.078*	.621*	383	.247	.014
Total Bacteria	1.74	9.26	127	.241	-.041
Streptococci	1.026*	.202*	383	.009	-.032
Pool Size	106,272	63,209	383	-.156	-.014

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 19

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

Type of Filter, Part 2 -- Pressure Diatomite

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.313	0.462	241	1.000	0.480
Turbidity Load Factor	.750	1.875	201	.480	1.000
pH	7.46	.384	242	-.116	.088
Temperature °F.	78.2	4.63	160	.003	-.209
No. of Swimmers	76.1	131.	224	.190	-.118
No. Swim/12 hr	137.	240.	202	.192	-.138
No. Swim/1000 gal	.398	.507	224	.189	-.163
No. Swim/12 hr/1000 gal	.885	.941	202	.207	-.201
Chlorine Residual	1.039	.578	205	-.036	-.075
Coliform	1.090*	.637*	242	.083	-.012
Total Bacteria	7.60	24.0	56	.029	.054
Streptococci	1.012*	.143*	242	.083	.029
Pool Size	142,641	187,603	242	.084	-.121

TABLE 20

Type of Filter, Part 3 -- Vacuum Diatomite

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.380	0.605	104	1.000	.378
Turbidity Load Factor	.768	2.068	93	.378	1.000
pH	7.54	.297	105	.142	-.210
Temperature °F.	79.4	3.48	82	.013	.121
No. of Swimmers	250.	459.	94	-.087	-.138
No. Swim/12 hr	424.	655.	94	-.048	-.168
No. Swim/1000 gal	.663	.840	94	.026	-.181
No. Swim/12 hr/1000 gal	1.327	1.268	94	.132	-.242
Chlorine Residual	1.030	.508	95	-.251	-.051
Coliform	1.104*	.692*	105	.102	-.048
Total Bacteria	2.12	4.68	30	.151	-.018
Streptococci	1.028*	.217*	105	.045	-.044
Pool Size	263,283	207,149	105	-.054	.134

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 21

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

Pool Location, Part 1 -- Indoor

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	0.271	0.484	184	1.000	.322
Turbidity Load Factor	.748	1.86	172	.322	1.000
pH	7.55	.270	184	.128	-.056
Temperature °F.	81.4	3.13	146	-.231	-.004
No. of Swimmers	18.5	14.0	182	.113	-.184
No. Swim/12 hr	42.6	36.5	172	.434	-.120
No. Swim/1000 gal	.231	.199	182	.199	-.179
No. Swim/12 hr/1000 gal	.549	.502	172	.429	-.151
Chlorine Residual	1.15	0.500	184	-.210	-.095
Coliform	1.082*	.634*	184	.309	.020
Total Bacteria	5.07	20.3	78	.004	-.036
Streptococci	1.021*	.179*	184	.058	-.033
Pool Size	95,169	54,286	184	-.095	.134

TABLE 22

Pool Location, Part 2 -- Outdoor

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.321	.452	568	1.000	.451
Turbidity Load Factor	.741	1.76	449	.451	1.000
pH	7.45	.36	568	.031	.066
Temperature °F.	77.3	4.9	413	.043	-.045
No. of Swimmers	97.6	232.	510	.016	-.105
No. Swim/12 hr	192.	367.	459	.047	-.139
No. Swim/1000 gal	.407	.563	502	.112	-.164
No. Swim/12 hr/1000 gal	1.026	1.189	451	.138	-.211
Chlorine Residual	.969	.557	481	-.121	-.053
Coliform	1.110*	.718*	570	.089	-.018
Total Bacteria	2.28	9.52	138	.229	-.046
Streptococci	1.021*	.186*	570	.026	-.012
Pool Size	175,792	201,222	562	-.0005	-.005

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 23

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

Pool Ownership, Part 1 -- Governmental Agency

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.389	.484	178	1.000	.437
Turbidity Load Factor	.755	1.79	154	.437	1.000
pH	7.37	.321	178	-.051	.031
Temperature °F.	77.6	5.44	139	.104	.057
No. of Swimmers	243.	353.	170	-.035	-.175
No. Swim/12 hr	441.	538.	156	-.028	-.223
No. Swim/1000 gal	.74	.77	170	.110	-.240
No. Swim/12 hr/1000 gal	1.43	1.31	156	.090	-.289
Chlorine Residual	1.063	.538	171	.005	-.023
Coliform	1.172*	.902*	180	.061	-.029
Total Bacteria	1.11	3.37	34	-.086	-.081
Streptococci	1.022*	.210*	180	.055	-.035
Pool Size	365,403	256,822	180	-.108	.038

TABLE 24

Ownership, Part 2 -- Motels

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.314	.491	150	1.000	.512
Turbidity Load Factor	1.146	2.578	114	.512	1.000
pH	7.63	.384	150	.086	.043
Temperature °F.	76.4	5.59	94	-.163	-.109
No. of Swimmers	6.3	6.9	134	.050	-.216
No. Swim/12 hr	26.0	27.2	114	.262	-.227
No. Swim/1000 gal	0.149	0.161	134	.0006	-.233
No. Swim/12 hr/1000 gal	.616	.719	114	.190	-.214
Chlorine Residual	.86	.672	127	-.125	-.038
Coliform	1.200*	.983*	150	.289	-.007
Total Bacteria	8.08	17.99	22	-.189	.804
Streptococci	1.020*	.140*	150	.129	-.044
Pool Size	42,131	11,982	150	.077	-.004

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 25

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

Ownership, Part 3 -- Schools

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.245	.512	114	1.000	.320
Turbidity Load Factor	.837	2.272	112	.320	1.000
pH	7.51	.24	114	.118	-.062
Temperature ^{o}F.	81.3	1.88	96	-.134	-.152
No. of Swimmers	18.7	13.5	114	.185	-.253
No. Swim/12 hr	38.9	34.6	112	.404	-.168
No. Swim/1000 gal	.198	.162	114	.371	-.199
No. Swim/12 hr/1000 gal	.447	.470	112	.491	-.130
Chlorine Residual	1.133	.452	114	-.261	-.064
Coliform	1.000*	0.000*	114	.000	.000
Total Bacteria	.785	2.86	60	.456	-.071
Streptococci	1.017*	.187*	114	-.042	-.033
Pool Size	107,531	46,435	114	-.260	.074

TABLE 26

Ownership, Part 4 -- Private Clubs

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.292	.414	256	1.000	.462
Turbidity Load Factor	.528	.815	205	.462	1.000
pH	7.44	.343	256	.130	.064
Temperature ^{o}F.	78.0	4.45	198	.069	-.130
No. of Swimmers	35.3	61.3	226	-.060	-.160
No. Swim/12 hr	82.1	92.4	213	.0004	-.226
No. Swim/1000 gal	.293	.341	218	.069	-.171
No. Swim/12 hr/1000 gal	.878	1.125	205	.115	-.208
Chlorine Residual	1.018	.527	203	-.275	-.189
Coliform	1.066*	.538*	256	.107	.009
Total Bacteria	4.61	19.74	84	.059	.326
Streptococci	1.027*	.205*	256	.010	.050
Pool Size	115,742	65,842	248	-.135	.058

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 27

STATISTICAL ANALYSES OF VARIABLES
EXCLUDING WADING POOL SAMPLES

Ownership, Part 5 -- Private Organizations

Variables	Average	Standard Deviation	Number of Samples	Correlation with Turbidity	Correlation with TLF
Turbidity	.247	.350	54	1.000	.504
Turbidity Load Factor	.349	.390	36	.504	1.000
pH	7.51	.321	54	-.121	.129
Temperature ^{o}F.	81.1	3.94	32	-.025	-.021
No. of Swimmers	18.7	15.4	48	.085	-.076
No. Swim/12 hr	57.0	49.8	36	.245	-.383
No. Swim/1000 gal	.310	.259	48	.098	-.086
No. Swim/12 hr/1000 gal	.924	.783	36	.299	-.385
Chlorine Residual	1.028	.475	50	-.064	-.264
Coliform	1.000*	0.000*	54	.000	.000
Total Bacteria	3.79	14.98	16	-.091	-.303
Streptococci	1.000*	0.000*	54	.000	.000
Pool Size	60,207	13,764	54	-.149	.175

* Actual number of coliform and streptococci organisms not determined. See explanation on pages 17 and 18.

TABLE 28

FREQUENCY DISTRIBUTION OF TURBIDITY *

Type of Filter (Part I)

All Categories		Sand	
Number of Samples (N) = 752		Number of Samples (N) = 383	
Average Turbidity = 0.309 JTU		Average Turbidity = 0.279 JTU	
Standard Deviation = 0.460		Standard Deviation = 0.406	
% Samples	Turbidity	% Samples	Turbidity
6.6	0.013	5.2	0.012
13.3	0.025	10.4	0.018
19.9	0.037	15.7	0.023
26.6	0.048	20.9	0.030
33.2	0.060	26.1	0.040
39.9	0.085	31.3	0.044
46.5	0.120	36.6	0.060
53.1	0.160	41.8	0.075
59.8	0.26	47.0	0.110
66.5	0.35	52.2	0.140
73.1	0.45	57.5	0.167
79.1	0.68	62.6	0.21
89.5	1.00	67.8	0.26
93.0	3.00	73.0	0.32
100.0	4.1	78.3	0.42
		83.5	0.49
		88.7	0.68
		94.0	0.93
		100.	3.0

* Wading pool samples not included.

TABLE 29

FREQUENCY DISTRIBUTION OF TURBIDITY *

Type of Filter (Part II)

Pressure Diatomite		Vacuum Diatomite	
Number of Samples (N) = 241		Number of Samples (N) = 104	
Average Turbidity = 0.313 JTU		Average Turbidity = 0.380 JTU	
Standard Deviation = 0.462		Standard Deviation = 0.605	
% Samples	Turbidity	% Samples	Turbidity
4.15	0.010	4.8	0.013
8.3	0.015	9.6	0.030
12.5	0.027	14.4	0.035
16.6	0.038	19.2	0.042
20.8	0.044	24.1	0.050
24.9	0.055	28.8	0.060
29.1	0.060	33.7	0.067
33.2	0.073	38.5	0.110
37.3	0.090	43.3	0.120
41.5	0.100	48.0	0.168
45.6	0.120	53.0	0.180
49.5	0.146	57.7	0.21
54.0	0.163	62.5	0.27
58.1	0.20	67.3	0.30
62.2	0.22	72.2	0.38
66.4	0.26	77.0	0.45
70.5	0.28	81.8	0.54
74.6	0.35	86.5	0.72
78.8	0.39	91.2	0.82
83.0	0.50	96.2	1.2
87.1	0.72	100.	3.8
91.3	0.98		
95.5	1.20		
100.	4.1		

* Wading pool samples not included.

TABLE 30

FREQUENCY DISTRIBUTION OF TURBIDITY *

Ownership

Part 1 -- Local Governmental Agency

Number of Samples (N) = 178
Average Turbidity = 0.389 JTU
Standard Deviation = 0.484

% Samples	Turbidity
6.1	0.020
11.7	0.037
20.0	0.053
28.4	0.085
39.5	0.140
49.5	0.214
60.0	0.30
74.5	0.45
85.5	0.80
100.0	2.8

TABLE 31

Part 2 -- Motels

Number of Samples (N) = 150
Average Turbidity = 0.314 JTU
Standard Deviation = 0.491

% Samples	Turbidity
8.7	0.020
18.0	0.037
23.3	0.053
33.3	0.085
45.4	0.140
54.6	0.21
69.2	0.30
79.2	0.45
93.2	0.80
100.0	4.1

* Wading pool samples not included.

TABLE 32

FREQUENCY DISTRIBUTION OF TURBIDITY *

Ownership

Part 3 -- Schools

Number of Samples (N) = 114
Average Turbidity = 0.245 JTU
Standard Deviation = 0.512

% Samples	Turbidity
19.4	0.020
37.0	0.037
47.6	0.053
56.4	0.085
66.1	0.140
72.3	0.21
77.5	0.30
86.4	0.95
92.5	0.80
100.0	3.8

TABLE 33

Part 4 -- Private Club

Number of Samples (N) = 256
Average Turbidity = 0.292 JTU
Standard Deviation = 0.414

% Samples	Turbidity
9.5	0.020
20.9	0.037
32.3	0.053
42.5	0.085
50.8	0.140
64.6	0.21
73.2	0.30
79.2	0.45
87.9	0.80
100.0	3.0

* Wading pool samples not included.

TABLE 34

FREQUENCY DISTRIBUTION OF TURBIDITY *

Ownership

Part 5 -- Private Organization

Number of Samples (N) = 54
Average Turbidity = 0.247 JTU
Standard Deviation = 0.350

% Samples	Turbidity
7.4	0.020
14.8	0.037
37.0	0.053
46.3	0.085
59.3	0.140
64.8	0.21
74.1	0.30
83.4	0.45
90.8	0.80
100.0	1.7

TABLE 35

Pool Location

Indoor Pools		Outdoor Pools	
Number of Samples (N) = 184		Number of Samples (N) = 568	
Average Turbidity = 0.271 JTU		Average Turbidity = 0.321 JTU	
Standard Deviation = 0.484		Standard Deviation = 0.452	
% Samples	Turbidity	% Samples	Turbidity
10.9	0.014	6.2	0.014
21.8	0.030	15.5	0.030
32.9	0.050	25.4	0.050
43.5	0.070	34.7	0.070
51.4	0.115	42.4	0.115
65.2	0.160	50.4	0.160
76.0	0.31	69.5	0.31
87.0	0.67	86.3	0.67
100.0	3.8	100.0	4.1

* Wading pool samples not included.

TABLE 36

FREQUENCY DISTRIBUTION OF TURBIDITY

Sample Location

Shallow End of Pool		Deep End of Pool		Wading Pool	
Number of Samples (N) = 346 Average Turbidity = 0.331 JTU Standard Deviation = 0.480		Number of Samples (N) = 342 Average Turbidity = 0.305 JTU Standard Deviation = 0.461		Number of Samples (N) = 54 Average Turbidity = 0.808 JTU Standard Deviation = 1.370	
% Samples	Turbidity	% Samples	Turbidity	% Samples	Turbidity
9.5	0.014	9.7	0.014	10.5	0.014
18.2	0.037	19.0	0.037	15.8	0.037
28.6	0.053	28.1	0.053	22.8	0.053
37.0	0.085	39.5	0.085	33.4	0.085
50.0	0.140	47.6	0.140	38.6	0.140
60.4	0.21	58.8	0.21	43.8	0.21
69.3	0.30	70.5	0.30	54.4	0.30
78.0	0.45	81.6	0.45	66.6	0.45
89.2	0.80	89.7	0.80	77.2	0.80
100.0	3.8	100.0	4.1	100.0	7.2

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